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Spatial Analysis and the Measurement of Urban Sprawl

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A Note on Measurements

The measures described in this section retain the measurement systems used in the studies they are derived from. This made the results of the metrics easier to interpret and in the case of the landscape ecology metrics the FRAGSTATS software (McGarigal and Marks, 1995) used in calculating the metrics converts the coverage projection units to hectares. As an aid to conversion the following conversion factors apply:

- 1 acre = 0.004047 km2
- 1 hectare = 0.01 km2
- 1 square mile = 2.589988 km2
- 1m2 = 0.000001 km2
- 1 unit/acre = 25 units/ha
- 1 unit/hectare = 100 units/km2

Abstract

The thesis extends the research of the SCATTER project which evaluates the understanding of urban sprawl in Europe and examines methods for quantifying sprawl. The thesis extends this by examining the extent to which the definition and identification of sprawl is influenced by the nature of the indicators and measures used, and on the scale at which they are applied. It assesses the suitability of measures used in the US context for the polycentric pattern of European cities. Measures used in the European context have been based on land use densities – this is extended to incorporate measures based on urban form and land use patterns.

The findings highlight the difficulties inherent in defining and measuring sprawl, as sprawl is a complex phenomenon with experts in the regions often unable to agree on the patterns and consequences of this type of urban growth. It is not so much a specific land use pattern or set of patterns as a manifestation of concerns which are common features of modern urban growth - regardless of urban form - and which emerge from the emphasis of interpretation and the dimensions of interest to local administrators and land use authorities.

The research has identified that measures are sensitive to the spatial area used - even areas with some similarities, such as county and travel to work areas or district and urban areas do not produce consistent results. In Europe therefore measuring sprawl is also complicated by the fact that self contained subcentres set in low density rural areas may contribute to sprawl in the city centre, yet this is not identified by traditional measures of sprawl which assume that areas related to the urban centre are contiguous.

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Chapter 1

Introduction

1.1 Semantics of Sprawl

The phenomenon of urban sprawl has received extensive attention in the literature particularly since the 1980's, but despite this wealth of information there has been little progress illuminating the nature of sprawl's impact on urban form and urban function. Much of this debate assumes a general agreement over an ideal urban form - usually the compact, self sufficient city- which is often rooted in debates on urban sustainability.

Despite the diverse nature of the arguments, certain common elements can be extracted. Sprawl is compared to the ideal of the compact city, and for the most part, emerges as a poor loser. In terms of urban sustainability sprawl is perceived as a somewhat negative urban form with costs outweighing benefits – these commonly include un-aesthetic development; poor access to services for those with limited mobility such as the young and elderly; increased trip lengths, congestion and increase in fuel consumption; overwhelming dependence on automobile use; higher costs of neighbourhood infrastructure; and loss of agricultural land and open space. These perceived negative effects are tackled with urban policies which attempt to restore a more compact urban form by channelling development to the city centre, and attempting to set physical limits to growth.

Sprawl in its most extreme form is expressed in the North American landscape, as 'a specific, and dysfunctional, style of growth' (Ewing et al., 2002, p.3)

In a nutshell, this style of growth entails rapid, uncontrolled, residential and non residential growth in rural and undeveloped areas, growth with wide separation of uses, which is typically characterized by uniform low density housing divorced from services and retail development.

The vague nature of current definitions of sprawl is perhaps best summed up by the rather purple prose of Andres Duany, champion of the New Urbanist movement, who states "It will be sprawl: cookie-cutter houses, wide, treeless, sidewalk-free roadways, mindlessly curving cul-de-sacs, a streetscape of garage doors - a beige vinyl parody of Leave It to Beaver. Meanwhile, more cars will worsen your congested commute. The future residents will come in search of their American Dream, and in so doing will compromise yours " (Duany et al., 2000, p.4). For traditionalists, sprawl is everything ugly, every dissatisfaction with modern urban living. The solution is a retreat to the nostalgia of the past through the re-creation of small town America.

It is not surprising that sprawl has also been called 'one name for many conditions....it explains everything and nothing...conflating ideology, experience and effects.' (Galster et al., 2001, p.682). Attempts have been made to hone the rather woolly definitions of sprawl using quantitative measures based on the characteristics or impacts of sprawl and its urban form. These measures identify sprawl based on the densities, land use, accessibility patterns and monocentric structure of the North American city, which in many characteristics is distinct from the European experience.

Despite the wide variety of measures applied there has been little agreement on how to operationalise the measurement of sprawl. The results of previous studies are inconclusive, with measures identifying differing levels and patterns of sprawl for the same areas: the confusion stemming in part from the use of a variety of definitions, the application of measures to inconsistent geographic and administrative areas, and disagreement on the level of density applicable to the term urban sprawl.

For example, many definitions of urban sprawl use the concept of low density to identify sprawl, however, what is considered low–density is relative and varies with each country's cultural expectations. For instance, in the US low density is development of two to four houses per acre while in the UK low density would consist of less than eight to twelve houses per acre.

A second barrier to clear definitions and measures of sprawl lies in the scale at which urban growth and sprawl is identified. Cities can be seen as parts of a wider socio – economic network, as in discussions of polycentricity or as distinct physical entities. This is reflected too in the literature on sprawl which includes scales from low level physical concerns at the site development and neighbourhood level, to much more abstract pictures of how cities are growing within a region in terms of population and employment.

A typical example is the case of polycentric systems, which are often described both as intra-urban patterns of clustering of population and economic activities (London, Paris, Milan) and inter-urban patterns such as the Dutch Randstad, the Flemish Diamond and the area of Padua, Treviso and Venice in Northern Italy.

The spatial scale at which urban sprawl is measured impacts on the issues identified as problems of sprawl and on the most appropriate measures and indicators for monitoring. It is also crucial to select the proper territorial scale in policy design and implementation in order to remove institutional barriers and ensure cooperation between different institutional players: one of the first questions facing local/regional authorities who wish to set up a platform of cooperation is identifying the most appropriate area for tackling sprawl.

There is also a temporal dimension in the issue of how to define and measure urban sprawl. As sprawl emerges, it is characterized by differing forms and functions, for instance moving from very scattered residential development, to progressive densification, with the addition of retail and public services, and culminating in further densification and evolution to autonomous urban centres, with the provision of jobs for residents (CASA et al., 2005). Urban sprawl can therefore also be considered as part of the process of an evolving urban region.

Urban population is still growing and the growth of cities is a significant phenomenon. As an example of what was suggested above, but at a broader temporal scale, there was some discussion at the United Nations (1998) of urban growth following a pattern of "urban transition" and urban sprawl corresponding to a phase of this growth. The first phase is of fastest growth in the core of the city, termed urbanization in the United Nations report ; the second phase is suburbanization with fastest growth just outside the city core; the third phase is counter urbanization, with population in the core and suburbs moving out to more rural areas, and the fourth phase is re-urbanization with an increase in population in the core of the city. According to this model, the phenomenon of urban sprawl would fall into the third phase of growth.

1.2 International Expressions of Sprawl

Interest in the forms of modern urban growth is not confined to the North American city, but has been explored in the European context, where sprawl has different outcomes and effects on urban areas. The SCATTER (Sprawling Cities and Transport from Evaluation to Recommendations) project conducted by CASA together with five European partners, investigated the nature and problems of urban sprawl in Western Europe (CASA et al., 2005). The SCATTER project examined methods to understand and control urban sprawl in Europe from a land use / transport perspective, with particular emphasis on congestion, air pollution, and energy consumption. It examined measures to control urban sprawl and to identify the efficiency of suburban public transportation services under this pattern of growth.

The first stage of the project examined the theoretical nature of urban sprawl in Europe, through a review of the impacts of urban sprawl, and a series of expert interviews in Brussels, Stuttgart, Bristol, Helsinki, Rennes and Milan. It also examined the nature of sprawl's impacts through a statistical analysis of population and job location, trip demand pattern, and air pollution using customized indicators.

The second stage of the project involved a review of policy measures which tackle urban sprawl. These were primarily transport policies which reduce congestion through a modal shift from private car to suburban public transport. The project examined the paradox faced by policies to control sprawl which often end up solving one problem and creating another. For instance, the higher levels of accessibility which are created through increased road capacity and greater accessibility of suburban public transport, create an incentive for urban sprawl by increasing access away from the city centres. By examining the impacts of the infrastructure projects in tandem with the impact on urban sprawl, the projects create an integrated land use / transport dimension.

This is used as a basis for the third stage of the project, which models the impacts of urban sprawl by looking at the land use / transport implications of three transportation projects in Brussels, Stuttgart, and Helsinki, and evaluates the likely impact of these projects using a set of transportation indicators.

This research is used to provide a set of recommendations to European cities, together with an urban sprawl monitoring tool, which can be used as a base for identifying whether further detailed work on urban sprawl is necessary for particular cities. This project will be discussed in more detail in chapters four and five.

SCATTER is one of a number of European projects examining the problems of unconstrained urban growth in Europe. The projects have a common aim to identify the nature of urban sprawl in a European context, in light of the dominant focus in the literature on the North American expressions of sprawl. The SELMA (Spatial Deconcentration of Economic Land Use and Quality of Life in European Metropolitan Areas) project (Valenzuela et al., 2003) examines the sprawl of economic land use, as opposed to residential sprawl – the focus of SCATTER.

SELMA examines the deconcentration of industrial, commercial and office activities from the urban centre to the suburbs, focusing on the quality of life impacts resulting from this type of 'economic sprawl'. The project identifies a typology of economic sprawl, using quantitative measures in combination with a subjective assessment based on the interpretation of maps and expert opinion. The increase in the use of measures for identifying sprawl highlights the need for a more systematic understanding of the suitability of measures developed in the North American context for interpretation of urban sprawl with European densities and spatial scales.

Quality of life, as defined by the SELMA project, corresponds to the costs of sprawl occurring at a city wide or metropolitan scale. It examines the supply of new jobs and the growth or decline of jobs between the inner city and suburbs, jobs housing balance, capital and operating costs of infrastructure, travel patterns and commuting times, the spread of non residential sprawl and its impact on public transport, aesthetic impacts, social cohesion, availability of services and contribution to inner city decline.

The project examines 14 case study areas to identify the forces of deconcentration, the extent of deconcentration, common patterns of economic dispersal and the impact on quality of life for the central cities and suburbs. Economic deconcentration is measured in terms of employment, and floor space / land consumption, with sprawl characterized not only by deconcentration of jobs, but also by the relationship between job growth and loss in the central cities and suburban rings.

No clear typology of sprawl is identified – rather the variations in patterns of economic deconcentration are categorized by the strength of the planning system. The sprawl of non residential development is seen as separate from residential sprawl – with a form that is often more contiguous and covering a wider extent of the urban area.

In contrast to SCATTER, the project focuses on the sprawl of economic activity rather than the sprawl of residential development. The perspective of SELMA is that the movement of economic activities to the urban fringe contributes to urban sprawl. However, discussions of residential sprawl place the movement of economic activities to the suburbs as intra urban polycentricity, seen as a more sustainable urban form.

The discrepancies between SELMA and SCATTER highlight the lack of a clear definition of sprawl and lack of established methods of measurement. Effects of sprawl are location specific and vary across the metropolitan area. SELMA, with its contrasting of the impacts of sprawl on the inner city and suburbs, also emphasizes the importance of the scale of the urban territory in identifying urban sprawl and its impacts.

A study of sprawl at a regional scale, conducted by the ESPON (European Spatial Planning Observation Network) project (Helsinki University of Technology et al., 2004), has examined the nature of urban sprawl in Europe with an interest in understanding the principal territorial trends at a scale across Europe as a whole. As such the emphasis has been on understanding the morphology and relations between regions, as part of a national and European hierarchy of urban areas – which complements the metropolitan scale of projects such as SCATTER and SELMA.

ESPON examines the morphology of polycentricity, specifically the dominance of cities within a network of peripheral / dependent cities, and the relations and flows between cities. It is primarily focused on the macro level of polycentricity - to spread regional development more evenly across the European territory. However, the meso level of linkages between complementary cities in different regions and the micro level of city clusters within a region are recognized. The level of polycentricity is measured in terms of indicators of size, location and connectivity among FUAs (Functional Urban Areas), which comprise a core urban agglomeration or contiguous built-up area, plus adjacent commuting municipalities.

ESPON specifically discusses polycentricty at the intra urban scale with the identification of four settlement structures: sprawl – a contiguous urban fabric with no settlement groupings, monocentric – a large grouped urban structure with no secondary cities, polycentric – several grouped structures which remain independent of each other and scattered – characterized by small scattered settlements. Cities were characterized by concentration of area, proportion of settlement area to total area and ratio between first and second ranking settlement areas. The study found that the use of settlement area as a proxy for importance caused some difficulty in less populated settlements, as in these cases major regional centres were often of an extent equal to minor surrounding towns. The measurement and understanding of sprawl in the European context, while having made great advances, is still open to discussion and remains difficult to quantify.

The inter relationship between the local and metropolitan scale of SCATTER and the regional/EU scale applicable to ESPON lies in the strengthening or decline of peripheral nodes within metropolitan areas, placed as building blocks in polycentric development strategies and new polycentric networks. The ESPON research explores ways of developing a polycentric network through enhancing urban competitiveness, linking the size and importance of cities - which is seen as providing a context for the ordered growth of cities and regions through enhanced complementarity and urban networking. This feeds into discussions of sprawl as cities are encouraged to enhance economic integration to improve their ranking in national urban systems. A second key issue is the provision of a framework for cooperative governance across administrative borders, which also has ramifications for the control of urban sprawl.

Policies for polycentric development set out by ESPON encourage regional policy measures which include spatial implementation instruments, non spatial instruments and strategic planning instruments, all of which can reduce or increase the spread of urban sprawl at the metropolitan and city scale. Spatial implementation instruments are regional policy measures which impact on the economic development of a specified area. Non spatial instruments include administrative reforms which remove barriers to cooperation between neighbouring cities or between core and peripheral municipalities, and strategic planning instruments include broader spatial visions which encourage the promotion of polycentric development.

1.3 Thesis Aims and Structure

The research focus of the thesis is to examine measures of sprawl in functional and administrative areas in the counties of the UK, and the ability of measures based on urban form and density to identify sprawl in the UK and Europe . As discussed in chapter three, there is no clear definition of sprawl, despite the voluminous literature on the concept, and the use of quantitative measures is one attempt to provide a clearer definition. There has been little previous exploration of the influence of spatial scale on the identification and measurement of urban sprawl, and the thesis therefore explores the impact of scale on the identification of urban sprawl, and also explores the suitability of the administrative area in defining and measuring sprawl, as opposed to the functional area. Previous work has focused exclusively on the administrative area, however, sprawl is a phenomenon which extends across individual urban boundaries.

The thesis compares the identification of sprawl through the examination of measures using the county, district, urban and travel to work areas. It also compares the ability of three types of measures to identify sprawl, namely, measures of density, measures based on patterns of residential clustering (derived from residential segregation measures) and measures based on land use (derived from landscape ecology measures), details of the methodology are set out in chapter six. The focus is on the UK, however, the nature of sprawl is similar to that in the rest of Europe, as discussed in chapters five and six, in its levels of density and the polycentric nature of its cities.

Research carried out for the SCATTER project, provided quantitative indicators of sprawl for six case cities of Brussels, Rennes, Milan, Helsinki, Bristol and Stuttgart. These measures resulted in the identification of characteristics and impacts of sprawl across a range of urban forms. However, it was not clear whether the identification of 'sprawl' even in the absence of a typical sprawl form was limited to the case cities or due to the variation in scale among the case cities. The thesis expands on this by examining the issue of scale and by examining a wider range of indicators than was used in the SCATTER project. The SCATTER project focused primarily on the change in sprawl over time, using measures of density with one measure of spatial autocorrelation, while the thesis holds constant for time by focusing on one period only. Through the examination over varying spatial scales and through the use of a wide range of indicators (both density indicators and indicators based on patterns of clustering and land use) the thesis examines whether indicators of sprawl consistently identify the phenomenon in a European context.

1.3.1 Thesis Structure

Chapter 2 opens with a discussion of the nature of urban growth in Europe. This frames the context for discussions surrounding the definition of urban sprawl, which can be seen as a particular type of urban growth. Chapter 3 continues by exploring the nature of urban sprawl, particularly its position within the framework of debates on urban sustainability. This is contrasted with debates on the nature of sprawl in the United States, which tend to revolve around the issue of costs of sprawl at a neighbourhood scale. An understanding of this dichotomy is important in evaluating the type of measures used in the United States and their applicability to the European context.

Chapters 4 and 5 examine the research of the SCATTER project, focusing in particular on the results for the case city of Bristol. This section evaluates the in-depth interviews to develop a qualitative understanding of urban sprawl. The view of sprawl provided by the experts is compared with the quantitative measures used in the project, and used to assess their suitability for measuring sprawl, therefore providing a complementary understanding of the main issues and patterns of sprawl.

Chapters 6 and 7 examine the measures of sprawl. Chapter 6 outlines the methodology used, and chapter 7 the outcomes. The measures are presented in three sections: the first section uses standard density measures, examining their performance over different urban scales; the second section looks at measures based on dwelling and business patterns derived from a neighbourhood geography; and the third section examines measures based on land use / land cover patterns. These sections extend the dimensions of the measures used in the SCATTER project, and examine the assumptions made by the SCATTER project on the urban scales and urban forms used as a basis for measuring sprawl. Chapter 8 discusses the main conclusions with relevance to the SCATTER project and provides direction for future study.

Chapter 2

Urbanization and Decentralization

2.1 Spatial Patterns

This section discusses patterns of urban growth and change in Europe. This review of the structure of cities and regions provides conceptual consolidation for the definition of urban sprawl used in the study, the geographical scales examined and the relevance of the measures to the patterns of urban growth in Europe. It will be shown that urban sprawl is not so much a new urban form but merely a feature of modern urban growth The study of urban sprawl can be seen not so much as an investigation of a new phenomenon but as a new perspective on long existing patterns of urban growth and change. The necessary factors discussed are the broad institutional forces shaping urban change in Britain and Europe, and the spatial patterns arising out of these changes.

The phenomenon of urban sprawl has received extensive attention in the literature particularly since the 1980's, but despite this wealth of information the debate on the impact of sprawl on urban form and function remains undecided. Much of this debate assumes an ideal urban form which is the anti thesis of sprawl – this taking the form of a self contained, compact city - the roots of which can be traced to cities of the past, including the Mesopotamian city, the Greek polis, and the medieval walled city. Despite their diverse nature, certain common elements can be extracted. These cities had small populations by modern standards, were limited in physical size with a clear demarcation between rural and urban, and provided the main focus of economic and cultural life.

Nevertheless, urban sprawl is not a new phenomenon – although the term was first used in the 1820's in England (Whyte, 1957) – sprawl can be traced back to Roman times, evident in the breaking ot formal planned cities, where the processes of growth created enormous urban complexes. The Roman grid collapsed internally through breaches in the street system along with the collapse in municipal planning, while beyond the city the attraction of new public foci outside the gates of the established city centre, led to an urban landscape which dissolved into a maze of streets and alleys crammed across the landscape (Kostoff, 1991; Mumford, 1961).

Critics of suburbia date almost from the date of its inception - William Cobbett (1830) author of Rural Rides, as early as the 1820's declared, riding west from London, that "all Middlesex is ugly... a sprawl of showy tea-garden-like boxes" (Cobbett, 1830, p.1). Following the passage of time this growth of the suburbs mushroomed and solidified with the rise of mass transportation during the nineteenth century, its early form shaped by the extension of the railways out to the suburbs during the 1850s-1920s, resulting in a radial spread with the central district connecting suburb to suburb. As the means allowed, the congestion and foul conditions of the industrial town led to an escape to the suburbs - and later the development of the garden city (Geddes, 1915). The ideal of the suburbs is embodied by Ruskin (1876) who speaks of 'building more, strongly, beautifully, and in groups of limited extent, kept in proportion to their streams, and walled round, so that there may be no festering and wretched suburb anywhere, but clean and busy streets within, and open country without...'

However, it was this mass movement to the suburbs that finalized the suburban alienation from the city resulting in its post war embodiment – seen as the death of the suburban ideal and the rise of urban sprawl. The suburban refuge became a mass of uniform, unidentifiable houses facing increased congestion from commuters, a lack of public transport and other services. The pedestrian scale imposed by the railways disappeared – despite having low densities – the railway suburbs remained tied to the railroad line, limiting the spread of the suburb, with houses in walking distance of the rail stations, and shops and parking concentrated around these nuclei. Natural green belts in between the rail lines helped create small self contained but linked suburban communities.

The rise of the automobile as a means of transport resulted in a further wave of urban sprawl, increasing the scale of the suburbs freeing it from all constraints, creating an anti urban pattern of low densities and far flung urban functions. A disaggregated, sprawling form, with specialization of individual parts (Hall, 1997; Mumford, 1961; Whyte, 1957). Apart from the planned cities of socialist Europe, this sprawling, un-regimented growth can be identified as a common characteristic of the modern urban landscape.

2.2 Socio Economic Influences on City Form

Despite the diversity of patterns of sprawl, common elements can be identified which influence the growth of European cities, and the emergence of patterns of urban sprawl in Europe. This section will explore these factors before moving on to examine some recent patterns of urban sprawl and the associated costs.

Patterns of urban sprawl at the local, city wide and metropolitan level can be seen not just as the outcome of land use processes but as part of broader demographic, economic, social and political trends. The current urban patterns are the result of these global pressures acting upon urban settlements which in turn are countered by the ability of urban settlements to retain pre-existing settlement structures and hierarchies in the presence of these forces of change (Batty, 2001; Hall et al., 2001).

Urban sprawl should be distinguished from urban growth – the latter should be sustainable, while the former is not. As soon as cities began to grow, there was concern about their size. In the ancient world, Rome was the first city to reach a population of one million with the consequence that in the first and second centuries AD, the city was subject to series of Imperial edicts limiting its growth, but with little success. Similar attempts were made by the Courts of the Tudor Kings and Queens for 16th century London, where the notion of some sort of cordon, not only to protect the countryside but to stop the plague, was seriously proposed (Morris, 1994).

Sprawl is often referred to as being 'uncoordinated growth': the expansion of community without concern for its consequences, in short, unplanned, incremental urban growth which is often regarded unsustainable. Despite this dichotomy between urban growth and sprawl, the nature of sprawl forms and the costs associated with sprawl suggest that sprawl *is* modern urban growth. Concerns about urban growth are long in existence and what is seen as sprawl today is often the sustainable development of tomorrow- dependent on the normative expectations of society for its towns and cities. For example, in the early and mid 20th century, sprawl was often confused with suburban development and there was considerable disquiet with the way lower density urban living was becoming the dominant way in which peoples' aspirations about living in cities were moving. But in one sense this was a reaction to something new and the early suburbs now appear to be considerably more coordinated than the kinds of developments which have taken place in the last 25 years, particularly in North America.

It cannot be over emphasized that the scale at which urban sprawl is studied influences the identification of causes, costs and patterns of sprawl – with ramifications for the design of suitable measures and indicators. The focus of the North American literature on the neighbourhood level of sprawl precludes the understanding of sprawl as a local response to national or even global trends, emphasizing it as an anomalous pattern of urban growth, rather than the norm (Bruegmann, 1996; Burchell et al., 2000; Danielsen et al., 1999; Downs, 1999; Ewing et al., 2002; Gordon and Richardson, 2000; Weitz, 2001). Creating a clear definition of sprawl necessitates an understanding of the processes of growth shaping urban land use, including the influence of these trends on the dynamic and changing evolution of urban form over time.

2.2.1 *Growth Trends in European Cities and Territories*

After World War II, both Western Europe and the United States faced unprecedented increases in population, mobility and prosperity. On both sides of the Atlantic there were large demands for urban space, infrastructure and facilities. The result was a massive development that put pressure on the built and natural environment. However, the response in Europe and the US was different. The US responded to the 'crisis' with federal funding for mass produced housing – the most famous expression in the suburban development of Levittown - focusing on market methods to increase aggregate consumption through home ownership both as a remedy for the severe housing shortage and as a means of stimulating the economy (Clawson, 1971; Rome, 2001). Post war the US government provided loan guarantees for builders to obtain the capital needed for large scale building operations, and federally funded mortgage insurance programs allowed the mass of middle America to purchase a home with only a 5 percent down payment. As a result home ownership was often cheaper than renting.

European countries meanwhile tried to meet the increased demand through state intervention and planning. Between the 1970's and1980's in European countries, two simultaneous events opened the door to the first important wave of uncontrolled sprawl: the end of the welfare state, which dramatically reduced the level of national government subsidies to the housing sector and the misinterpretation of demographic trends which showed a decline in total population (the end of the baby boom) without realizing that the demand for new housing would increase due to a reduction in the size of households and lifestyle changes increasing the amount of movement out of the family home.

2.2.2 *Changing Urban Populations*

During the last two decades Europe has seen the emergence of new trends of demographic behaviour, family formation and household structure. Aspects of this "second demographic transition" are smaller households (75 percent of households now consist of 1 or 2 persons) and increased migration from Eastern European and North African countries towards the European core. This has been accompanied by the decline of the "traditional family" and the rise of immigrant areas within cities (Bontje, 2001; Hall, 1993). This shift is primarily due to the ageing of the population, the decline of fertility to below replacement levels, the decline in marriage rates and the rise in the age of marriage, the increase in cohabitation and the rise in divorce .

These demographic changes have resulted in new patterns of urban growth. The increased immigration and smaller households show a preference for central city locations with access to kin, supportive social and cultural institutions, and easy access to casual work (Bontje, 2001; Hall, 1993). Competition between these groups has created processes of gentrification in the inner city districts, often leading to social exclusion with higher prices leading to displacement of the disadvantaged out of the core and inner districts into the transitional zone (Smyth, 1996). In Europe these pressures force the population out of the city centre, creating a ring of low income residential development in the periphery. In addition, population growth is less able to explain the spread and pace of urban growth.

2.2.3 *The Influence of Economic Activities*

During the past half-century, European economies have moved from being fundamentally industrial economies based on the production and handling of goods, to informational and service economies (Castells, 1989; Hall, 1993; Storper, 1997). The rise of the knowledge economy has freed businesses from locational constraints, as constraints do not lie in the costs of moving goods between locations, but are determined by the need for face-to-face contacts. In this case, the benefits of a central location, are offset by the cost of office space and of attracting workers. For company headquarters, a central location is still important due to the need for high levels of interaction. However back office functions are more often located in cheaper non-central locations. While there is some argument that information and service activities remain dependent on demands from the industrial sector (Gershuny and Miles, 1983), locationally services are no longer tied to production, which enables greater locational choice and more disintegrated urban patterns.

Another significant trend linked with the shift towards more flexible production is the emergence of spatially contiguous innovative industrial clusters consisting of large numbers of SMEs (Small and Medium Enterprises) that concentrate in order to exploit the benefits of networking (Simmie, 2001; Van Den Berg et al., 2001). These clusters can lead to the formation of industrial districts specializing in specific industrial sectors. These trends thus promote both spatial concentration and dispersal depending on the industrial process and sectors in operation.

At the inter-urban scale economic trends result in a concentration of jobs for sectors such as business services, high-tech service and cultural industries, while at the local level there is a de-concentration of these jobs towards the fringes and outer rings of urban areas. Among the possible spatial impacts of on-going economic changes, an important issue to be considered is the impact on commuting and the jobs housing balance, as this impacts on the land use transport implications of urban sprawl. The rise of functional centres outside the urban core has resulted in commuting flows outward, with greater interconnection between these peripheral centres.

According to Echenique (2001), distance covered by each trip has increased, together with a decrease in the number of short journeys implying that mobility is the result of longer trips. Trip length appears to be connected to urban density – where urban compaction is strong, there is a higher level of short trips, while long trip lengths have been facilitated by the supply of inter urban transport infrastructure.

The spatial distribution of commuting flows has also altered. Daily journeys are no longer for the largest part between suburb and city, but increasingly city-to-city and suburb-to-suburb. Though commuting flows between the suburban centres are still low, their importance is increasing. Radial transport connections, linear links from the surrounding municipalities to the central cities, still dominate and penetrate ever further into the areas around the cities. In outer metropolitan areas however, origins and destinations of trips are more diverse and thus more difficult to serve by public transit - particularly for suburb-to-suburb trips that do not follow the main radial lines to the centre. In contrast, public transport in suburban area is complementary to private transport, apart from some efficient city railway and express railway systems in large agglomeration areas and inter-city connections

Job decentralization has also resulted in a mis-match between jobs and skills of residents, resulting in unemployment even where the jobs housing balance is good. Proponents of this spatial mis-match hypothesis, originally formulated by Kain (1992) argue that job decentralisation harms low-income residents of central cities due to barriers limiting access to suburban labour markets. This hypothesis has been recently reintroduced in the debate on urban sprawl in the attempt to model and evaluate the impact of the distribution of population and jobs on commuting patterns and the costs of such patterns on individual and households (Arnott, 1998).

These growth trends have resulted in the movement of population and jobs out of the urban core, a movement often equated with urban sprawl. The sections on counterurbanization and polycentricity discuss the movement away from the urban centre, leading on to discussions of the relationships to sprawl shown in the case cities of the SCATTER project in chapters four and five.

2.2.4 *Counterurbanization*

The dominance of the decentralization of population and households from the urban core is noted in the work of Berry (1976) who popularized the term 'counterurbanization'. This term describes a movement of population away from the large urban centres - involving a negative relationship between net migration and settlement size - with the lower ranked, smaller sized settlements gaining a higher share of population growth than larger, higher ranked settlements. Previous population growth and concentration in urban areas was replaced by decreases in the size, density and heterogeneity of the central city. Berry's analysis of cities in the United States indicates that the process of decline was strongest in large metropolitan areas, with rapid growth occurring in smaller metropolitan areas, exurban counties outside the administrative boundary of the metropolitan areas but with strong commuting links, and in peripheral counties with no economic ties to metropolitan labour markets.

A similar pattern was observed in the United Kingdom, in this case termed 'accelerating decentralization', which involved a higher relative increase in population in the outer metropolitan rings, developing into an absolute loss of population in the centre by the 1960's (Champion, 1989; Drewitt et al., 1976; Hall et al., 1973). Decentralization included trends of job decentralization to the outer rings, as well as residential decentralization. Early stages consisted primarily of residential movement, with little decentralization of employment from the urban core, while the outward shift of employment accelerated in later stages of decentralization. Counterurbanization was not a return towards traditional rural areas, but the movement of population to smaller metropolitan areas and non-metropolitan areas. The counterurbanization movement involved two growth patterns, the first resulting in the spread of population into metropolitan peripheries. The second movement resulted in the rise of smaller settlements independent of the large urbanized centres, which will be discussed in section 2.2.5

The classic distribution is described by Walter Christaller (1966), first published in 1933, in his discussion of central place theory, which outlines a version of the 'rank size rule' governing the number, distribution and size of towns. Accordingly, the hierarchy of places is given in order of importance as major regional centres, provincial capitals, 'gau' centres (an administrative unit which was the German equivalent to an English shire county under the Nazi party), regional centres, county seats, office towns and market locations.

The hierarchy described by Christaller is determined by a threshold population necessary for the provision of particular goods and services, and the range of goods and services which is the maximum distance people will travel to purchase the good or service. Under counterurbanization however, there is a negative relationship between the rate of growth of a place and its size (Berry, 1960; Champion, 1989; Hall, 1974). In this case, the smaller urban places show a higher rate of growth, while growth in the larger metropolitan centres has slowed. This shift is detailed in Hall (2001) who gives the list of variables for ranking cities and the changing hierarchy from 1913-1998 in the UK, with the level of services provided used to generate the hierarchy of towns. The variables used for differentiation provide a range of higher to lower level services: these are listed as the presence of accountancy firms, banks, chamber of commerce, total weekly newspaper score, morning newspapers, evening newspapers, theatres, cinemas, TV studios, number of hotels, highest star hotels, university, FE college, medical school, number of hospitals, hospital bed index, football clubs, rail stations, and direct trains to London. In the UK the process of decentralization resulted in a drop down the hierarchy of industrial northern towns and seaside towns, with a rise of suburban and country towns (including historic and market towns) which also saw a rise in the level of services provided (Hall et al., 2001).

At the beginning of the 1980's a shift in the trends of urbanisation processes was observed – while in the previous decade the population of small towns and rural areas had higher growth than the central areas of most urban agglomerations, particularly those with large cities (Bontje, 2001). The discussions of counterurbanization while acknowledging spread and diffusion of the population, and the rise in population of small and medium size towns, remain focused on the idea of the central city as dominant within the urban metropolitan area and the region as a whole.

A reversal of the trend to decentralization has been noted since the 1970's in the largest cities in Northern Europe, despite smaller cities and rural areas continuing to gain population, with larger urban areas seeing population gains (Champion, 1989; Cheshire, 1999). According to Champion (1989) the UK was notably was the one of the few countries in Europe which continued to lose population from its urban cores during the 1980's. The towns which showed moves to recentralization (Cambridge, Oxford and Canterbury), are all medium sized, with strong historic cores, and a well educated, highly skilled population.

This rise of the small and medium town, and changes in the range of services and functions associated with such towns brings us to the second process pertaining to measures of sprawl, that of polycentricity, which describes the development of these independent subcentres.

2.2.5 *Polycentric Cities*

The rise of the polycentric city is pre-dated by the form 'megalopolis', a term first used by Jean Gottmann (1957). Megalopolis envisions a set of distinct communities or cities which together dominate the economic life of the region. For example, the term was used to describe the urban and suburban areas stretching from Boston to Washington, which formed an apparently continuous urban area. This interconnection developed out of competition between local governments for a portion of the economic growth generated by the port functions of the cities on the eastern seaboard. The main economic functions were maritime, manufacturing - particularly finishing industries, and commercial, financial and cultural functions. Early mention is also made by Schnore (1957) who distinguishes between suburbs and satellite cities, which provide jobs for their own residents and supply goods and services, in the form of manufacturing and retail trade.

Indeed, an even earlier precursor to the idea of megalopolis can be found in Howard (1898) with the idea of garden city clusters, as a regional organization of cities, with population growth accommodated in separate garden cities, each with their own governance but networked by rapid transport links, and sharing among them a range of services and amenities, so that the regional provision of services is greater than that which could be provided by any one city. Although the result is one of polycentricity, the main aim of his cluster model is not to provide a polycentric network but to preserve the garden city, by preventing urban development in the agricultural zone surrounding the city.

A related definition of polycentricity was provided at much the same time by Geddes (1915) who coined the term 'conurbation', literally the growth of a large conglomerate formed by the merger of several free standing towns. This term too was widely used in the early to mid 20th century by those discussing urban growth and suburbanization.

A connection between counterurbanization and megalopolis has been made by Hall (1974, p.391) who questioned whether urban areas follow "a process of inexorable growth from metropolitan area to megalopolis. But in fact, as metropolitan areas grow large, their rate of growth shows a clear tendency to slow down and then to reverse...does not this very process lead to the growth of Megalopolis?" The outward movement of population thus results not just in growth around the urban area but in the rise of small and medium centres independent of large urbanized areas.

This type of dispersed city and the emergence of polycentric spatial patterns has been described as a breakdown of the urban hierarchy, resulting in the rise of moderate sized independent centres with horizontal linkages, rather than the traditional vertical and hierarchical linkages (Hoyt, 1941). It is debatable however, whether the rise of such centres constitutes a breakdown of the hierarchy or rather a 'flattening out' with horizontal linkages increasing in importance. This type of dispersed city includes separate urban centres with the socio-economic characteristics of larger sized cities; rural service centres which include basic economic functions as well as rural service centre functions; and horizontal economic integration between cities, rather than the classic hierarchical linkages (Fisher and Mitchelson, 1981).

The modern form of megalopolis is found in the concept of polycentricity, which seeks to explain the pattern of city growth as a multinucleated structure, rather than the single centre of economic activity of the monocentric model. This term can be applied at a variety of scales, namely the intra – urban scale, the inter – urban scale and the mega scale (Davoudi, 2003). The intra – urban scale focuses on the clustering of residents and economic activity within one built-up area, typically stretching to the commuting hinterland of the core city – termed the 'city region'. The definition of this area has at various times moved between planning and administrative units, continuous built-up areas, urban agglomerations with a threshold population, the historic city and its commuting hinterland, and the area which is economically, socially and culturally dominated by the city.

The inter – urban scale examines clustering at a regional level such as the south east of England, similar to the earlier descriptions of megalopolis and the garden city as distinct cities which interact with each other socially and economically. Although the interaction is often measured by labour market flows, it is also felt that stronger ties of non-work trip generation activity and flows of resources and information are necessary to constitute a polycentric region. There is some discrepancy in the literature regarding the structure of the urban hierarchy considered to be a polycentric region. The definition may allow for the inclusion of smaller settlements while other authors define the polycentric region as a number of cities all of equal ranking (Champion, 2001; Dieleman, 1997). The inter – regional scale is used less for analysis of patterns of urban growth and more for spatial planning strategy (Davoudi, 2003). This scale has been applied on a European wide level, looking at the national level of the European Union as a linked polycentric structure.

The main scale of interest for this study is the intra – urban scale, as it is of most relevance to the measures of sprawl being examined, which are suited to a range of scales from the core urban area to the intra-urban, and to the impact of sprawl in the context of urban sustainability. At the intra-urban scale types of polycentric centre can be identified based on the functions associated with the sub centres within the region.

The main difference is between the polycentric city and what is termed the 'dispersed' city, depending on the level of interaction between centres. Champion (2001) identifies a spectrum of dependence: first from little or no interaction, with the polycentric city having the most independence from the large urbanized centres; then at the middle of the spectrum a minimum interaction between centres, such as commuting to work; and finally high interaction/interdependence where each centre provides a set of city level functions for the region. In this case functions are unique to each centre but go beyond the level indicated by its place in the urban hierarchy.

Definitions of the polycentric centre also include older towns which have grown and become incorporated into older urban areas, and the second type which are new centres divorced from the urban core (Anas et al., 1998). Telecommunications, information-intensive activity, deregulation and global competition have all meant that previous vertical integration within a firm now takes place externally among separate firms. In addition, firms develop network organizations, both of which lead to agglomeration economies. Anas et al. (1998) look at the agglomeration economies of firms in terms of the broader interactions and activities, such as commuting and urban services, which form the polycentric network are not considered.

Other typologies describe the process of development, in addition to the resulting urban structure. Three evolutionary branches of the polycentric city have been described by Champion (2001) as the centrifugal mode, the incorporation mode and the fusion mode. The centrifugal mode results from the dispersion of production and services from a monocentric city to smaller centres, which in time grow to equal the main centre in size. The incorporation mode also derives from a monocentric city, but incorporates existing smaller centres, such as small towns which which previously had little interaction with the main centre in employment or services, which then grow to rival the main centre. The fusion mode does not start from a monocentric city, but develops from several centres of similar size which grow and develop interconnections due to improved transport links (Champion, 2001).

A polycentric centre at its most developed contains high-order services and basic sector employment, in contrast to a dispersed suburban centre which remains dependent on the major urban area. Basic sector employment is employment that meets non-local demand, with goods and services exported outside the urban area. This usually covers industrial sector employment. It is contrasted with retail sector and residential sector employment. Retail sector employment is that which meets local demand, and does not export finished goods and services outside of the region. This usually covers retailing, food and construction services. Residential sector employment covers both basic and retail jobs. Examples of high order services are found in Hall et al. (2001) .

The importance of this type of horizontal networking on an administrative level, is expressed by Gottman and Harper's (1990, pg.133) reference to the US context, in terms of: "the lack of cooperation between interdependent communities causes similar difficulties in the management of metropolitan matters...". In the past this did not apply as cities grew by annexing suburban rings into their existing unit of government but the current trends see suburban areas incorporated as separate towns. This opposition of interests between competing sub centres has contributed to the problems of urban sprawl, as will be discussed in chapter 3.

A specific form of the polycentric region deserving special mention is the 'edge city', as this type of development pattern has also been included in definitions of sprawl (Galster et al., 2001). The term was popularised by Garreau (1992) to label cities developing at the edge of suburban freeway interchanges, and characterized by more than five million square feet of office space, over 600,000 square feet of retail space, a higher number of jobs than homes, single end destinations with high level of services, and a recently developed city. This term has caught the popular imagination but can be seen as part of earlier discussions of suburban cities (Baerwald, 1978; Erickson, 1983; Erickson and Gentry, 1985; Erickson and Straussfogel, 1986; Morrill, 1980).

The seminal paper by Baerwald (1978) describes the stages of development of the suburban city in the Twin Cities metropolitan area. The fully-fledged edge city is a progression from the suburban residential development of the 1950's, which attracted the first non-residential uses of industrial and wholesale uses. This early stage shows less diversification than metropolitan areas with a high degree of specialization. The second stage of the late 1950's to late 1960's is distinguished by improved transport links, which spawned a high level of commercial uses clustered around major interchanges and in strips along frontage roads, with the initial industrial and wholesale uses joined by the electronics and computer industry. The late 1960's and early 1970'saw the establishment of increased residential and office development due to rapid appreciation of land values in the suburbs. The fourth stage of the mid 1970's saw the filtering down of functions.

A main trigger for the attraction of commercial service is the increase in land values due to the accessibility of the freeway interchange (Erickson and Gentry, 1985). The pattern of commercial development tends to stretch along the interchange and its arterial roads, with multifamily residential uses stacked behind a commercial strip, with industrial development near the outer edges. Interestingly, a typical concentric pattern appears when arterial and frontage roads are lacking and the interchange serves a large firm, government facility or shopping mall, thus focusing development around the interchange (Erickson and Gentry, 1985).

There is relatively little mentioned about interaction with the CBD (Central Business District) but the CBD initially remains strong during early expansion when the suburban commercial centres served the local area with convenience goods and personal services (Erickson, 1983). Other typologies of suburban centres are based loosely on their connection to the central city through transport networks, which are described as new commercial centres in downtown extensions or reclaimed dock lands; metropolitan sub centres dependent on inner or middle suburb transport interchanges; edge cities accessed by highways, and lacking public transport services; and edge cities developed around public transport hubs (Hall, 1995).

Interestingly, this development of the freeway corridor was seen as a unique phenomenon, unlikely to be duplicated elsewhere, although this has proven not to be the case. It also differs from the CBD in the lack of functional interdependence between uses. However, the freeway corridor has also been seen as including multinucleation, due to agglomeration of firms seeking to increase demand from multi purpose trip making consumers, sharing of infrastructure and facilities in suburban office and industrial parks and reduction of inter firm transport and communications costs, for firms with horizontal linkages (Erickson, 1983).

One important question is whether the traditional monocentric model or the polycentric form best describe urban structure in Europe. This is crucial to valid measurement of urban sprawl as most of the measures initially assume a monocentric urban form. There is evidence that the polycentric model provides a better depiction of the urban structure for the long term, mainly due to fundamental changes in the social and economic relationships of cities (Davoudi, 2003).

These fundamental changes take place at a global and national scale and in turn impact on the regional and intra-urban levels. A key development is scale economic shifts, such as the forces of global trading whereby newly industrializing countries form international trading and manufacturing relations with older industrial nations. This is coupled with a shift in the economy from goods production and handling to information processing, which has led to the rise of new industrial complexes serving the high tech and electronics industries. This separation of production and the increase in the importance of high technology, information rich services such as banking and finance, and media services is reflected in spatial changes between and within cities.

At the regional level this has lead to the clustering of activity near major cities. This is especially so for industries requiring high levels of face to face interaction or access to large amounts of information. A counter outcome of this shift is at the city wide level where services concerned with information processing decentralize to cheaper locations in the suburbs or small and medium size towns, outside the major cities. This is particularly prevalent among manufacturing and warehousing uses which move to the suburbs for access to large areas of land and a location close to the blue collar workforce, research and development and high technology manufacturing near the rural fringe; and standard information processing such as insurance and credit card processing to suburban nodes with high accessibility, lower rents and close to clerical labour supplies (Hall, 1995; Hall and Pfeiffer, 2000)

The second factor in structural change has been change to transportation in the shape of increases in automobile use, associated development of the freeways, and the rise of hub airports. This shift to the private car has lead to residential development in the suburbs out of the reach of traditional public transport. It has also created a shift in the traditional radial pattern of the transport network, to a more dispersed pattern connecting suburb to suburb. In some cases, airport hubs have led to the development of new industrial clusters due to the increase in accessibility, such as in the Heathrow M4 corridor, and high speed train stations have lead to new subcentres in the suburbs. (Hall, 1995; Hall and Pfeiffer, 2000).

2.3 Summary

The movement of population and employment away from the city centre towards the suburbs and smaller urban centres is not new to debates on urban sprawl, but forms part of long standing discussions on urban agglomeration and counterurbanization. This pattern relates to sprawl both in terms of population growth on the peripheries of major urban areas, and through the development of small and medium sub centres independent of the larger urban area, particularly in terms of the edge city.

Stemming from this is the issue is whether 'sprawl' is occurring due to growth around the peripheries of these smaller subcentres. This brings to the fore the question of the appropriate scale for measuring sprawl. Is an intra-urban scale sufficient to capture urban sprawl for a network of subcentres, and is a scale appropriate for peripheral development around the urban centre likely to miss sprawl at the subcentre level. As will be discussed in chapter three, the literature on urban sprawl focuses discussion on the costs associated with this pattern of urban growth. The next chapter will focus discussion on what characterizes sprawl when looking at a polycentric region and how this can be conceptualized using quantitative measures.

Chapter 3

Sprawl and the City

Sprawl is a consequence of broader social, economic and political trends, and as analysis of the 'costs of sprawl' makes clear, the impacts associated with this urban form are features of modern urban growth in general. This section explores the idea of urban sprawl as a specific pattern of growth and aims to show that far from being an anomaly, urban sprawl cannot be distinguished from contemporary urban morphology. The definitions and characteristics of urban sprawl discussed in this chapter feed into the identification of sprawl and policies to tackle sprawl explored through the SCATTER project, discussed in Chapters 4 and 5, and in the analysis of further quantitative measures of sprawl in Chapters 6 and 7.

A plethora of definitions abound – sprawl has been seen as strip development, scattered development, leap-frog development, low density development, car-led development - the list is endless yet fails to enable an operationalization of sprawl and fails to identify a particular 'sprawl form'. Sprawl is directly identified with urban growth – as cities grow, they expand around their peripheries. This is the key to understanding and identifying urban sprawl – urban sprawl is a function of the modern urban form and as such is part of the fabric of modern urban cities. The measurement of sprawl in itself can lead to clearer definitions of the term, through clarification of the conditions and patterns of land use associated with urban sprawl and its impacts.

Achieving a clear definition is complicated by the contextual nature of urban sprawl – what is meant by the term varies from place to place, and time to time. In large part this stems from the normative nature of the sprawl argument, which revolves around value judgements of the lifestyles of city and suburban residents, such as the preference of individuals for low density living, and more broadly for the consumption and use of space (Audirac et al., 1990; Richardson and Gordon, 1993). For instance, it has been argued that sprawl is beneficial and reflects the needs of the market; however, interventions such as growth management disrupt this and create their own negative impacts, resulting in higher house prices, lost local output and jobs due to restrictions on commercial and industrial development (Richardson and Gordon, 1993).

The focus on economic efficiency in discussions of sprawl in the US context contrasts with the focus on sustainable development in Europe, where the concerns of city growth revolve around issues such as increased dependency on the car, and the use of single occupancy vehicles, with resulting traffic congestion, noise and air pollution (Commission of the European Community, 1990; Organisation for Economic Co-Operation and Development, 2001a, 2001b; Office of the Deputy Prime Minister, 2003). Clearly, the spatial concept of urban sprawl and its impacts, varies across space and between places.

Currently, sprawl is viewed as a negative urban form (as discussed in chapter two), with the exception of a few market led detractors who consider sprawl positively such as Gordon and Richardson (Gordon et al., 1989a, 1989b; Gordon and Richardson, 1986;1996a, 1996b, 1997a, 1997b, 1998, 1999; 2000; Gordon and Wong, 1985; Pendall, 1999; Richardson and Gordon, 1993; Richardson and Jensen, 2000). Policies to combat sprawl have been promoted in the United States under the idea of growth management, and in the United Kingdom through the concept of the sustainable city and the compact city. A clearer understanding of urban sprawl is necessary to track the progress of policies combating sprawl, and clear definitions and methods of measuring sprawl are a step towards this. Policies tackling these negative impacts of sprawl typically call for compact cities which channel development to the city centre, and attempt to set physical limits to growth through growth boundaries and land preservation. Without a clear understanding of the characteristics, levels and patterns of sprawl it is not possible to assess the necessity for these policies or evaluate their effectiveness.

What is needed to achieve greater understanding is a more objective look at urban sprawl, with discussion based on empirical evidence to inform debates. In addition, the current literature, with its focus on the suburbs and peripheral extent of the major urban area is narrow in its geographical scope. The suburbs do not exist in isolation, but in the context of relationships with both the major urban area and the wider metropolitan region. The process of suburbanization is therefore part of the larger process of urban growth. This will set the stage for a less value laden interpretation of urban sprawl, one which places it in the context of urban growth as a whole.

3.1 Definitions

As discussed in chapter two, the term 'urban sprawl' has been in use over the last 200 years. The rapid growth and expansion of cities during the industrial revolution was termed sprawl, defined primarily in an aesthetic sense. However, recent theoretical definitions see sprawl more specifically as 'uncoordinated growth' – growth which is unplanned and unsustainable. These definitions emerge primarily from the North American literature, and as such fit the reality of sprawl in its most extreme form. Findings from the SCATTER project, however, show that these definitions do not fit the European urban landscape which exhibits consequences of sprawl, while having different land use patterns, densities and scales of development. The thesis explores the use of quantitative measures to clarify the definition and understanding of urban sprawl in Europe, particularly with regards to the scale and density of development in Europe.

The term "urban sprawl" has been used loosely, making a precise definition difficult, but as well known definitions from the United States by Galster et al. (2001):

> "Sprawl has become the metaphor of choice for the shortcomings of the suburbs and the frustrations of central cities. It explains everything and nothing. Much of the confusion about sprawl stems from the conflation of ideology, experience and effects. A term so widely used cannot be easily dismissed as too vague for serious discussion. ...As a first step toward developing policies to deal with its causes or consequences, it would help both critics and apologist if agreement could be

reached on what sprawl is, and how to measure it empirically and compare its occurrence across a large number of urban areas." (Galster et al., 2001), p.2

Existing definitions are based on urban form, urban land use and the impacts of sprawl. There is agreement that sprawl occurs on the urban fringe, in rapidly growing areas but little other consensus has been reached. Sprawl has been variously defined in terms of its costs, with further complications due to changes in the characteristics of urban areas enacted by the process of growth. In addition a variety of urban forms have been covered by this umbrella term, as discussed below.

3.1.1 Definitions Based on Urban Form

Definitions based on the idea of urban form consider any non compact development pattern as sprawl. This ranges from "scattered" to "leapfrog" development, meaning discontinuous development away from an older central core, with development interspersed with vacant land (Clawson, 1962; Harvey and Clark, 1965; Lessinger, 1962; Whyte, 1957). Suburban growth around the urban fringe has also been defined as sprawl; in this case the development is a *contiguous* expansion of already existing development (Gottdiener, 1977; Gottmann and Harper, 1967; Self, 1961). Another form is of compact growth around a number of smaller centres, away from the main urban core (Clawson and Hall, 1973). This is similar to the multi-nucleated city, where the city is served by several centres, but the distinction between multi-nucleation and sprawl depends on the level of services offered by the centres and the level of interaction of the city centres with the surrounding suburbs. Figure 3.1 illustrates the patterns of compact development, continuous low density, linear development, polynucleated development and scattered development.

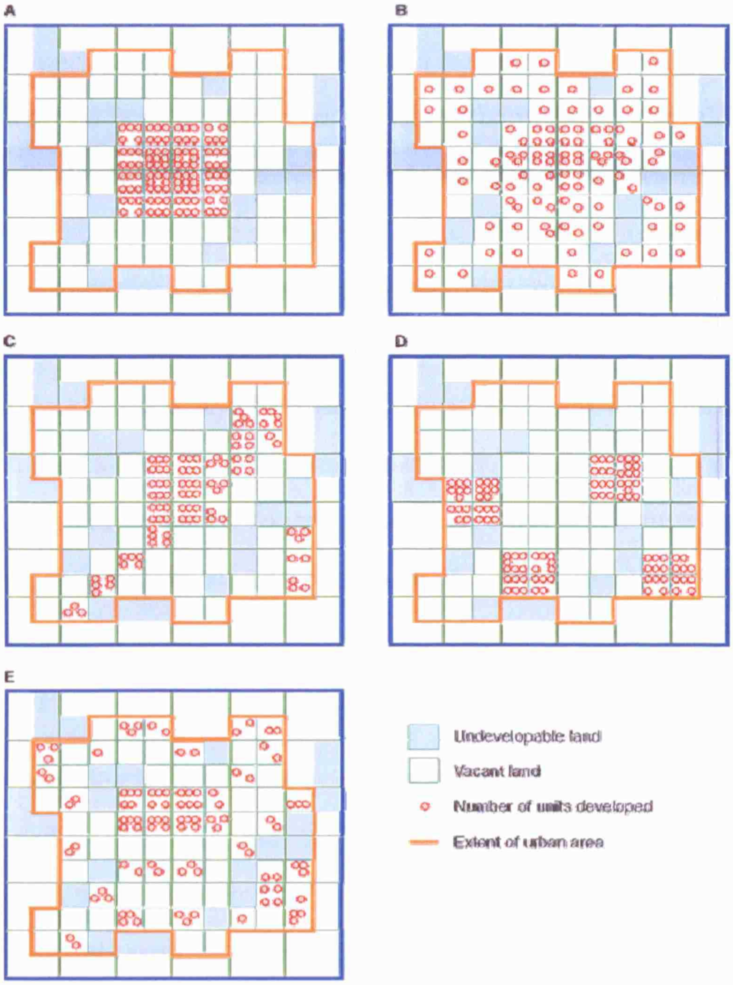

Figure 3.1: Patterns of urban sprawl.

(Clockwise from top left, compact development, continuous low density, linear development, polynucleated development and scattered / leapfrog development (after Galster et al. 2001))

One problem with these definitions is that developments as diverse as contiguous suburban growth and scattered development can both be classified as sprawl, although the causes and resulting impacts are vastly different. "Sprawl is a matter of degree" (Ewing, 1994), and lies somewhere in between these absolute forms, although where this may be is left as a matter of judgement. Ewing himself sees development moving from efficient polycentric urban patterns to the sprawl of scattered development. Further confusion results from the variation in scale of the definitions, for instance, linear development occurs at a neighbourhood level, and could be incorporated within scattered or contiguous development.

Debate has also revolved around the transformation of scattered development to continuous suburban forms over time. During the process of growth, infilling may occur, resulting in a more compact form (Clawson and Hall, 1973; Harvey and Clark, 1965; Ohls and Pines, 1975). In this case, sprawl is seen as reflecting the efficient workings of the urban land market. Land on the urban fringe is developed as demand for housing increases and profitability rises. Under this theory scattered development reflects land speculation, and the solution to sprawl therefore lies in a more efficient market for land transactions, together with increases in property tax to discourage speculation. Other economic arguments suggest that withholding land for speculation results in higher land values, and thus higher densities in the long term, although this is dependent on the pace of growth (Ottensmann, 1977). This idea of urban sprawl is to some extent peculiar to the US context where large tracts of empty land lie available for development, resulting in the encroachment of development onto rural land, in an unorganized manner with no focal points or nodes, or strung along highways with clusters of open space.

However, the main idea is that this is uncontrolled development, out of the reach of land use plans and programs (Lamb, 1983). The issues explored are also local in nature, focusing on the cost to provide public services, the reduction of agricultural land and other natural resources. Farms are divided into fragmented parcels which are uneconomical to cultivate, the drainage of marshlands increases risk of flooding and traffic problems increase due to strip development along major throughfares. However, this phenomenon of rapid urban growth beyond the bounds of townships and municipalities described in the US literature is not the main feature of European urban growth which is described as sprawl.

3.1.2 Definitions Based on Land Use

Clearly, urban form in isolation is not sufficient to identify urban sprawl, in fact similar land use patterns which fit the sprawl archetype on one dimension may actually be efficient on the land use dimension (Ewing, 1994). Definitions which take land use into account most often define sprawl as homogenous development, with a lack of services, poor accessibility and a lack of open space (Burchell et al., 2000; Downs, 1999; Peiser, 2001). For example, leapfrog development patterns have different impacts from economically efficient discontinuous development. Interestingly, definitions of sprawl in Portland, Oregon do not preclude urban growth, but see sprawl as 'the consumption of more land than is available in order to provide for urban activities, and when the services people need are very distant from each other' (CASA et al., 2005). Under this definition city boundaries are expected to move outwards according to the demand for housing and services but sprawl occurs when land is consumed in excess of the requirements for residential and service provision. So where does one draw the line between low density residential sprawl, polycentric development and exurban and rural residential development, which have similar development patterns but differ in the resulting land use and impacts?

Density is one criteria used as a proxy for development type. Although it is difficult to pin down a specific number, low densities have been cited as densities of 494 to 988 houses per km^2 (two to four houses per acre) have been cited for the US, in contrast to 1,977 to 2,965 houses per km^2 (eight to twelve per acre) in Great Britain (Clawson and Hall, 1973). This serves only to highlight the contextual nature of sprawl where higher densities are still perceived as sprawl in the European context. Low densities are associated with several costs of sprawl – at low densities greater reliability of car transport is necessary, while consumption of open land and the cost of servicing infrastructure is higher. High density is also seen as creating vitality and diversity. Large concentrations of people result in a wider range of high end services and urban functions (Jacobs, 1961). High density is often associated with high rise building – with densities of 24,710 to 49,419 persons per km^2 (100-200 persons per acre). Despite this high density at the building level, many high rise estates in the UK were built in large areas of open space, with overall densities no higher than the surrounding housing. Density at the city scale was therefore much lower, and in terms of the effects of sprawl, insufficient for public transport. Although density is one of the key components of definitions of urban sprawl, it is insufficient to characterize sprawl, let alone to identify it on the ground.

3.1.3 *Definitions Based on Impacts of Sprawl*

Another alternative definition is based on the impacts of sprawl (Ewing et al., 2002; Johnson, 2002; Razin and Rosentraub, 2000). It provides an alternative to definitions based on urban form, and is based on the idea that the distinction between sprawl and other urban forms is a matter of degree. Importantly, given the difficulty of identifying a specific physical form, it is the consequences of sprawl which are of importance rather than the physical form. Ewing (1994) has identified important consequences as poor accessibility of related land uses, and lack of functional open space as a way to identify and define sprawl. It is suggested that sprawl can be defined as any development pattern with poor accessibility among related land uses, resulting from development which is not concentrated and which has homogenous land uses.

The problem with a definition based on function is that it assumes there are negative consequences to sprawl and creates a temptation to label any development with negative impacts as "urban sprawl". Indeed, defining sprawl in terms of its costs, such as poor accessibility and lack of open space should be avoided, as this creates a tautology when discussing the impacts of sprawl.

Despite this diversity of forms and definitions, there is an assumption that the urban form is monocentric, and most definitions identify sprawl as leap-frog or scattered development, with a focus on the density of development and its distance from the city centre. However, too many urban types are lumped together under the term sprawl, as each type will have different characteristics and impacts. In addition, development at the urban fringe is simply classed together with no distinction of its internal form, such as inner and outer suburbs.

The definition used by the SCATTER project incorporates all three dimensions, bringing in the political and administrative dimensions of urban sprawl. Sprawl is seen as 'uncoordinated urban growth' – that is the expansion of community without concern for its consequences. This reflects growth which is unplanned, incremental and unsustainable. This definition can be applied to a variety of scales of development, acknowledging that while high density neighbourhoods can exist, when placed within a context of uncoordinated growth this often leads to low density, piecemeal development typical of urban sprawl.

3.1.4 US and European Definitions

Despite this wealth of definitions, sprawl remains difficult to identify. Current definitions encompass numerous development patterns and a wide range of impacts. One is left asking: how many of these characteristics must be present for an area to be classified as sprawl? Is there a difference between 'normal' patterns of growth and urban sprawl? These conceptual definitions although they provide some understanding of the phenomenon, do little to help identify urban sprawl on the ground, and remain biased to North American land use patterns of urban form.

Definitions of sprawl in the literature coming out of the US position sprawl in terms of costs to the individual, rather than placing it within the context of costs to the community which is more common to the European debate on urban sustainability. Significant issues such as the jobs-housing balance, congestion, and energy costs are not considered as dimensions of sprawl, although they are discussed as impacts. This also reflects the positioning of sprawl at a neighbourhood level in the United States, rather than the intra and inter urban scale in Europe.

This reference to the individual is reflected in the early literature on urban sprawl which focuses on the development process, particularly problems of suburbanization for residents and developers, without however, fully formalizing the types of urban patterns under discussion. For example, Pacione (1993) focuses on the process of urbanization in the creation of sprawl in Britain, linking it to the struggle between private capital and public planning which plays itself out in the urban fringe – a possibility opened up by the existence of a less regulated space where public-private conflicts can come to the fore. The main arenas of conflict lie in the builder / developer pressure for development in the green belts, as a need to meet demand for housing. In this view new construction regenerates the local economy, against regulatory pressure to restrain development in lieu of long term costs to local authorities, loss of agricultural land, pressure on infrastructure and opposition to green field development in favour of inner city regeneration.

At this point there is no clear answer to a working definition of sprawl, with agreement only that it occurs on the edge of urban areas which are experiencing rapid growth, and that sprawling cities are unstable and undergoing continuous change. In its most extreme case, urban sprawl takes the form of scattered development and would consist of homogenous, low density residential development, although even this is difficult to identify empirically. Sprawl is thus contextual and attempts to seek an absolute definition have resulted in such vagueness that sprawl has become a metaphor, covering all and any negative aspect of the city.

3.2 Local Level Context and Causes

Chapter two outlined the broader influences on urban growth and sprawl while this section outlines the local and neighbourhood level context and causes of sprawl. As discussed in section 3.1 observations on local context and causes of sprawl are rooted in the North American experience. At this level the main causes revolve around the demand for housing, changes in travel costs and competition between administrative units.

The movement out of the city centre is seen by advocates of the free market approach as a result of consumer demand for low-density single family housing on large lots, (Cullingworth, 1960; Self, 1961; Audirac, Shermyen, and Smith, 1990; Danielsen, Lang, and Fulton, 1999). According to this view demand is driven by individual preferences where

> "the ideal of owning a single family home, the need for an adequate environment for raising a family, a strong desire for privacy, and the appeal of a rural ambiance are among the most prominent reasons for choosing suburban and exurban locales."(Audirac, Shermyen, and Smith, 1990, page 473).

Evidence for this is based on consumer preference surveys. In Florida, the Bureau of Economic and Business Research Survey, (Audirac and Shermyen, 1989), showed that the least preferred locations were the suburbs of major cities and the suburbs and downtowns of small cities; and the most preferred locations were the downtowns of major cities and rural and semi rural areas (Audirac, Shermyen, and Smith 1990). Further evidence, is provided by the American LIVES survey (1995) and the National Association of Home Builders (NAHB, 2002). The LIVES survey showed that 20 percent preferred New Urbanist communities with higher density subdivisions, 50 percent preferred New Urbanist design with standard subdivision densities and 30 percent preferred standard suburban communities. The NAHB survey traded off house size with commuting time to work and services, and showed that 83 percent preferred a detached house in the suburbs over a town house in the city. Surveys, however, provide only indirect evidence. Another approach could look at the market demand for different housing types through data on house sales. The lack of available housing in the central cities meant that the population had to be accommodated elsewhere. In the case of the US, the outward movement of residential population began in the nineteenth century. This trend increased in the post war era, and included the movement of not only residential development but also manufacturing and services, fuelled by higher levels of income, increased personal mobility and improvements in transportation.

The supply of housing to meet this demand has been fueled by public subsidies. In the US these took the form of federal assistance on mortgages through the 1932 Federal Home Loan Bank Act and the Veterans Administration, which financed existing mortgages and provided mortgage insurance for home buyers. These provided home financing to a wider range of income groups through low down payments, with lenders insured against mortgage defaults. Further incentive was provided by deductions to income tax through home ownership – deductions were given for payment for real estate taxes and interest on home mortgages (Jackson, 1985). The importance of this argument is that it affects whether consumer demand can be altered by government policy. This appears to be the case but there is also evidence that the preference for single family housing changes with household size and level of income, with demand for better quality housing rising as income rises (Clawson, 1971).

Enabling the growth of the cities and the changes in housing demand has been the change in the dominant mode of transportation, with the development of the private automobile and the corresponding growth of the highway system. There is some debate in the literature over the influence of public subsidies versus market forces in the growth of automobile use. There are claims that this growth, and by extension the increase in urban sprawl, is due to government subsidies for automobile use (Ewing, 1994; Jackson,1985). This increase in private transport and the subsequent decline of public transportation to the suburbs is attributed to government having "taxed and harassed public transportation, even while subsidizing the automobile like a pampered child" (Jackson, 1985, p. 170).

This change in mode of transportation by providing increased mobility and allowing for the outward movement of the population is perhaps the single most important enabling factor leading to urban sprawl. It should be noted that the growth of the suburbs with the increase in automobile use is a North American phenomenon and does not explain the development of urban sprawl in the UK. In Britain, the growth in the public transportation network was more important in the development of suburban housing. In London, for example, the growth of the suburbs began with the extension of the rail network to the suburbs in the 1860's, producing a radial pattern of growth along the lines of transportation. The latter development of a more widely spread, circular pattern of growth was also a result of the development of public transportation, in this case by motor bus. The private automobile played little part in the development of urban sprawl. New modes of transport can be seen merely as an enabling factor allowing access to undeveloped areas at further distances from the city. However, it is also claimed by Clawson (1971) that the economic advantages of suburban living are more important in the creation of sprawl than changes in transportation. This may certainly be true in Europe.

A further aspect of urban growth which is often neglected is the change in the administration of the city. There are two issues, both of which are important for data collection. In the first instance, the legal boundaries of the city may not coincide with the functional or economic units of study. In these cases, the suburban or sprawl areas may lie outside the legally defined city. Data collected for the legal city may not cover city – periphery interactions. The question to be asked is what is the appropriate area of study, and for which areas are data available. A concept such as the US Census

SMSA (Standard Metropolitan Statistical Area), includes functionally related areas in a region. Although this is convenient for data collection, some thought must be given to deciding the spatial area that best represents the relation of the centre or centres to the periphery.

The second consideration is the change to the boundary of the city due to annexation of areas on its periphery. These changes to the legal boundaries of the city are important when comparing data over different time periods. Although the city is nominally the same, it can refer to a different spatial area at different periods in time (Clawson, 1971). In these instances, care must be taken to adjust the data for differences in spatial area.

3.3 Sprawl and the Compact City

It is not the intention in this section to provide a comprehensive review of the compact city and its contribution to sustainability; therefore the discussion will focus on the relation of the compact city simply to urban sprawl.

Discussions of urban sprawl are also guided by theoretical concepts of the compact city which in the European literature are positioned as the antithesis of urban sprawl and presented as the most sustainable urban form (Burton et al., 2000; Williams et al., 1996). It is important to consider this concept given that measures of sprawl assume a monocentric urban form, with dispersion from the central core, thus measuring the extent of deviation from the ideal of the compact city. Utopian visions of the compact city have ranged from Le Corbusier's Ville Radieuse, in which high density, high rise buildings would provide energy efficient living, with 95 percent of the ground remaining open, his aim being to provide a vertical garden city with reduced commuting times. Higher income residents would be housed in lower densities around the courts, with shops and amenities nearby to provide a high level of diversity (Corbusier, 1967).

At the other extreme lies the equally utopian vision of the new urbanists in the United States, pioneered by architects Andres Duany and Elizabeth Plater-Zyberk (Duany et al., 2001) following closely the position advocated many years ago by Jane Jacobs (Jacobs, 1961). This vision calls for a revival and recombination of traditional urban elements, using a traditional grid street pattern, with narrow streets and short blocks. It advocates the return of the main street, with a streetwall of shops, as part of a commercial node within walking distance of most residences. The town centre gains prominence with a mixture of residential and retail uses, placing civic services and amenities near the centre of town. The New Urbanist vision is a replica of the classic American small town of the early twentieth century.

In the US the approach to the sustainable city has taken the form of 'smart growth' policies (Danielsen et al., 1999; Downs, 2002; Hollis and Fulton, 2002; Katz, 2000a; Nelson, 2002; Weitz and Moore, 1998). Smart growth is a term covering a series of ad hoc policies promoting sustainable development at the community level. It encourages use of public transport, pedestrian activity, mixed uses and preservation of open space. That main focus is on the benefits to the community and to the environment. Policies range from what would be considered basic planning practice in Europe to policies which are more specifically identified with sustainable development. Examples include the provision of services through development impact fees, zoning tools such as conservation easements to preserve open space, development of recreational trails, pedestrian retail areas, discounted parking for car pooling, fiscal policies such as exemption from capital gains for home buyers in the city centres, and mortgage discounts for buyers in the vicinity of transit service.

One of the earliest (and often cited as the most successful) examples of such policies is the Portland urban growth boundary. In this sense the idea of smart growth can be traced back to Lewis Mumford (Mumford, 1938) who espoused the idea of the green belt to provide open space and to limit the boundary of an urban area. This was part of his overall idea of cities as part of a regional structure – occurring as regional centres, similar to the garden city of Howard, with population growth focused in new towns planned as satellite cities to existing metropolises. This would allow cities to retain a 'human scale', and a functional balance between home, work and shops. The first urban growth boundary was implemented in Salem, Oregon in 1973 under the Oregon Land Use Act of 1973, which required that growth be planned in a way that provided for an orderly transition from rural to urban land use. Although the focus was primarily to preserve agricultural land, the urban growth boundaries (UGBs) were consistent with other smart growth principles as providing an orderly and economic provision of public facilities and services, and providing for employment and liveability. Portland UGB was proposed in 1978 and approved in 1981 (Nelson and Moore, 1993). The UGB has been successful in increasing the density of urban development and slowing the area of developed land – from 1980-1994 the metropolitan population increased by 25 percent while the urban land increased by only 16 percent, with density of new development by 1998 at 1976 dwellings per km^2 - 8 dwellings per acre (Gibson and Abbott, 2002). Interestingly, the UGB is seen as to 'reproduce the city of the Middle Ages where the concentric boundaries of the city progressively move outwards according to the growth of the demand for activities and housing development.' (CASA et al., 2005, p.104).

There is no overarching national policy document, although policies implemented have similar goals to those of the compact city: mixed land uses within compact neighbourhoods, open space protection, transit oriented development and revitalized downtowns. Despite promotion at the Federal level, development decisions are seen to be the purview of local government, resulting in policies which are implemented at a city wide rather than regional level, which can lead to growth being displaced to municipalities which do not practice smart growth. Smart growth policies are difficult to implement in the US as fragmented governance makes coordinated planning difficult, and weak regional governance, means planning powers are slim. Given the weak planning powers of state and local governments, the policies rely largely on fiscal incentives to achieve planning goals.

3.3.1 Compact City and EU Policy

The most comprehensive outline of EU policy on compact cities is found in the European Spatial Development Perspective. The guidelines for the three national, regional and local levels advocate

> " the development of a polycentric and balanced urban system and strengthening of the partnership between urban and rural areas. This involves overcoming the outdated dualism between city and countryside." (Commission of the European Community, 1999, p.19).

The policy on the whole focuses on the spatial scale of the European Community - looking at the transnational level rather than the city region, with the aim to create a polycentric structure of cities and regions across the territory of the European Union with a graduated city ranking. There is implicit support for the compact city, although within a polycentric framework. This is evident from the goals listed for the sustainable development of individual towns and cities, which are to increase the economic potential of 'gateway cities', with smaller towns and cities serving as regional centres. These centres in turn will be used to revitalize rural areas in decline.

Secondly, the goal is to diversify the economic base of smaller towns and cities which impact on the regional economy. Sustainable development of towns and cities is to be achieved through control of the physical expansion of towns and cities; a mixture of functions and social groups, wise and resource saving management of the urban ecosystem, better accessibility by different types of transport which are not only effective but also environmentally friendly, and the conservation and development of the natural and cultural heritage (Commission of the European Community, 1999). These broad goals all match the characteristics of the compact city.

The CEC policy lays out more explicit guidelines for city form, advocating the 'compact city' defined as the 'city of short distances', as a way to control the expansion of cities, including minimisation of expansion within the framework of careful location and settlement policy. The regional context is vital as it is only possible to stop the expansion of towns and cities, when the interests of the urban and rural areas are reconciled.

Details of the compact city are not well defined in the EU policy, but it should be noted that discussions of the compact city are set within the framework of the polycentric development of the European regions. In some ways, this provides the missing link tying the individual city to the wider spatial scale. The EU goals provide a balanced settlement structure through an integrated hierarchy of cities and regions, which extends through the interregional, transnational and EU levels.

3.3.2 *The Compact City in the UK*

In the UK context, the compact city is defined as a city with a centralised form, which is self contained, with high urban densities and integrated land uses. Policies advocating the compact city advocate intensification, which includes redevelopment of existing buildings or previously developed sites, sub division or conversion of buildings, building of additions to existing structures, and development of green sites within the city. Claims for the compact city are shorter travel distances, lower fuel emissions, preservation of rural land from development, support for local facilities and greater autonomy of local areas.

In the UK sprawl and its anti thesis the compact city are set in the context of urban sustainability, which provides some theoretical context for a definition. The application of this general concept to urban growth can be understood through policies such as the Urban White Paper, and the Sustainable Communities Plan (Department for Transport Local Government and the Regions, 2000; Office of the Deputy Prime Minister, 2003) . The fast growing population in the South East and the Thames Gateway with a growth rate of 5.7 percent between 1991 and 2000 highlights the pressures of growth and potential for further urban sprawl. Pressure for growth across the region is likely to increase with plans for 120,000 new homes in the Thames Gateway, 133,000 new homes in Milton Keynes/South Midlands, with further growth targeted to London-Stanstead Cambridge, and Ashford, and plans for jobs growth of 120,000 -180,000 in Thames Gateway with 120,000 – 150,000 jobs in Milton Keynes/South Midlands.

The main aims of the Sustainable Communities Plan for the South East, is to accommodate this growth in sustainable communities. A typical example of the ideal of sustainability can be seen with plans for Stratford (East London) which would utilize a 6000 km^2 brownfield site. This would promote mixed use schemes which will be integrated with the existing town centre, utilize existing transport links with plans for an International Passenger Station and CrossRail, provide community facilities, job growth of 10,000 by 2015, and create a network of parks accessing water features, the River Lea and Lea Valley Park.

Policies addressing the compact city such as Planning Policy Guidance Note 13 aims to integrate planning and transport, by increasing sustainable modes of transport, increasing accessibility to jobs, education and health facilities, shopping, leisure and local services, and reducing the need to travel, especially by car. The built form of the compact city is suggested, with urban infill and brownfield redevelopment as a priority, the second priority being urban extensions and new development around public transport nodes. Increased densities are emphasized at 30-50 dwellings per hectare net, with even higher density at public transport nodes. Mixed use development is also favoured for jobs housing balance, with employment to be located in city centres and near public transport nodes, and in town, suburban and local centres.

The Urban White Paper – "Our Towns and Cities: The Future" (Department for Transport Local Government and the Regions, 2000) discusses the decentralization of population and employment from towns and cities in the United Kingdom. The paper deals mostly with urban regeneration issues but it does explicitly mention brownfield redevelopment for the provision of new housing over development of greenfield sites. The series of "Sustainable Communities" plans which implement the Urban White Paper at the local level, focus on the need for new housing, also emphasizing the use of previously developed land. They suggest that higher densities from building at 2000 dwelling units per km^2 to 3000 dwelling units per km^2 will provide substantial savings in land consumption.

The wealth of policy suggests that the idea of the compact city is firmly entrenched in UK planning policy. However the compact city focuses on the city in isolation, out of context to its surrounding region, while many impacts on the city are determined by interactions of cities within the region, for instance by journey to work flows. As such several aspects of sustainability would be overlooked at this geographical scale.

An interesting consideration for urban sustainability in the UK is the use of green belts for managing city growth. In the UK the green belt has provided containment of the city, but at the same time encouraged deconcentration at the regional level (Champion, 2002). Post World War II policies of containment saw excess population transferred from existing cities to self contained New Towns. However the extent of the natural population increase and in migration was not catered for, resulting in sprawl from these towns, and population deconcentration across the urban hierarchy, rather than in planned self contained communities. The physical result has been fairly compact cities in the conurbations and free standing towns, with a concentration of new developments in pockets around smaller cities, towns and villages.

The socio economic impact of the resulting development pattern reflects many of the concerns associated with urban sprawl, due to the separation of residences and services, and socio spatial segregation. Most new development in the UK has been on the edges of existing towns and cities and is suburban in its characteristics; for instance, new housing estates although provided with basic services, remain dependent on the central city for provision of employment and higher level urban amenities. Even new towns which have a high jobs housing balance, and were planned for self containment, have high levels of commuting to the central city. New housing developments particularly in terms of commuting and travel distances reflect the characteristics of urban sprawl.

However, there has been some increase in the level of services to the suburbs, so although uses remain segregated, the movement of manufacturing and service jobs to the suburbs of larger cities and outside their green belts, and the rise of out-of-town shopping centres, has provided more access to jobs and services for suburban residents (Champion, 2002). However, it is not clear if these changes to the character of the suburbs increase the costs of sprawl. Despite the potential for reduction in travel times, the use of public transit remains low, with the private car as the dominant mode of transport. Thus far it is not clear if suburb to suburb commuting and trip distances are lower than suburb to centre commuting, as no clear empirical evidence exists for this.

3.3.3 *The Compact City: Theory and Reality*

This said, despite being the focus of UK planning policy, identification and monitoring of the compact city has not been straightforward. The spatial concept of the compact city focuses on urban intensification and consolidation, while processes of growth and pressure for growth outside the city boundary have largely been ignored. Indeed, the 'optimal city size' has not been established - that is, the physical size and density beyond which the advantages of agglomeration decrease due to diseconomies of scale. These negative externalities impact on the physical, economic and social environments of cities, in the levels of pollution, congestion and intensive energy use, high urban rents, social friction in the labour market, urban health problems and loss of cultural heritage, the very factors which initially led to movement out to the suburbs (Camagni et al., 2002; Capello and Camagni, 2000). The growth potential of cities at a static physical size is limited, therefore linkages outside the cities, at scales such as the city region and sub national region need to be considered.

In addition to debates on optimal city size, there is concern over the physical limits to growth of the compact city. While there is agreement with the goals of the compact city, that is urban intensification to protect the natural environment and a greater mixture of uses to enhance urban living, it may not be possible to achieve strict centralization given the strong trends to counter urbanization in Western countries, which has been discussed in chapter two. In addition housing costs and property costs are likely to rise, so urban infill alone is unlikely to meet the supply of new homes. Calculations are based on the assumption of single family homes, rather than higher density housing, but even so there is little likelihood of accommodating growth without town cramming and loss of green space (Breheny,1992).

The extent of urban land available for brownfield development is limited. Approximately 50 percent of new development could be accommodated on brownfield sites given the expected level of household growth of 3, 554,000 between 1996-2011 for England (Champion, 2002). A significant amount of new housing would therefore be on greenfield sites. Measures of urban sprawl have taken the compact city form as a baseline, with sprawl identified by the extent of deviations from this ideal. From the above discussion, it is evident that this 'compact form' is likely to remain a theoretical ideal, therefore alternative settlement patterns will be examined as a basis for defining urban sprawl.

A variety of alternative sustainable settlement patterns have been suggested in the literature. Camagni et al. (2002) looks at land consumption and mobility for five urban patterns - infilling, extension, linear development, sprawl and large scale projects in the communes of the province of Milan. In this case urban areas are identified by visual inspection of plans and land use maps, termed a 'descriptive/intuitive' approach. This is highly subjective and a major weakness towards identifying sustainable or sprawling development patterns. Infilling building growth is described as infilling of free spaces in the existing urban area; extension as building in the immediately adjacent urban fringe; linear development building along the main transport infrastructure; sprawl as scattered development lots; and large scale projects as large housing projects at some distance from the urban area.

The results of the research indicate that land consumption is lower for more compact development types. The estimates of the environmental cost of mobility relate density to average trip time of public transport, with higher densities having lower trip times, which in turn generates higher public transport trips. In terms of mobility the lowest impact is associated with infill-extension, followed by extension-linear, sprawl and then large scale projects. Sprawl has the lowest share of public transport and large projects the lowest share of pedestrian trips.

Work by Rickaby (1981, 1987) also looks at urban form and energy use in an archetypal town derived from 20 British towns with population between 50,000 and 100,000. Urban forms were determined from land use maps and foot surveys. The first study uses the TRANUS land use transport model to evaluate growth in a construction of an archetypal town. Development was modelled in five development options, three options with development contained within the existing urban area, and two options with development in areas of peripheral expansion, located in existing subcentres, new development corridors along main routes, or a combination of both. Little difference was predicted in fuel use between the five options, and almost no variation in modal split between private cars and buses. The towns composing the archetypal town are all fairly compact and most journeys are journeys to work using private cars. The model suggests that towns this size do not incur costs of congestion which would encourage riders to use the public transport.

Later work modelling five other configurations of town relocates part of the existing population to the hinterland. In the first case this population is located in the centre with a density of 4550 persons per km^2; the second distributes the population along a radial linear development with a density of 1696 persons per km^2; the third in a dispersed nucleated pattern with population in satellite towns with a density of 3390 persons per km^2; the fourth in a linear development along minor rural roads with densities of 1096 persons per km^2; and for the fifth, population is located in small villages in the rural hinterland with densities of 2890 persons per km^2. The results of this model showed that concentrated nucleated and dispersed nucleated (patterns one and three) are more efficient in terms of fuel savings and transport benefits. The dispersed nucleated pattern is slightly lower in fuel savings than the concentrated nucleated pattern; however, there is less traffic congestion and greater availability of accommodation. Fuel savings in the dispersed nucleated are dependent on distance to the main centre, as a factor of trip length to jobs and higher level service in the centre. The model suggests that the polycentric pattern of separate but economically dependent sub centres would result in highest savings in fuel use.

Breheny (1992, 1996) defines five alternative forms of urban growth, urban infill, urban extensions, key village extensions, multiple village extensions and new settlements. Urban infill takes place within the existing town boundaries, with urban extensions at the edge of existing built areas on green fields or open land. Key village extensions occur within existing villages including development of the village as a service centre, this taking place within the village and on land at the edge. In this case surrounding villages receive little growth. Multiple village extensions are similar in nature to key villages but most villages in the area receive urban growth. The fifth pattern is new settlements of between 350 and 5,500 houses.

In terms of proximity of uses, another feature of urban sprawl - infill development - offers the highest access to employment. High tech industry is often placed at the urban periphery, for which urban expansion is closest, but public transport typically weak. Key villages, multiple villages and new settlements have few employment opportunities and require higher levels of commuting, although new settlements have the potential for self containment.

In terms of energy consumption, 'urban extensions' and 'new settlements' are least efficient, and 'urban infill' or 'extensions with strong centres' most efficient, with decentralized concentration somewhere in between. This result assumes traditional journey to work patterns focused on the city centre. However, the findings are altered by the occurrence of urban and job decentralization where most trips are from suburb to suburb, rather than suburb to centre. This type of journey pattern reduces travel distances and fuel consumption among suburban centres. In addition, this suggests that changes in energy consumption have been affected by life style changes resulting in an overall increase in travel, not simply due to the pattern of urban form.

Breheny is a strong advocate of the decentralized concentration which would concentrate development in separate urban sub centres, linked by improved public transportation systems, rather than the centralized approach of the compact city. There is less focus on placing development in new settlements as older new towns have shown no advantage in terms of journey to work patterns. New towns need to be large and isolated to be self contained or small free standing towns in close proximity to a larger urban centre in order to be energy efficient. There is little discussion on the ability of mixed centres to provide lower energy use, particularly for smaller towns where the goods and services provided would be non specialist, with work trips and higher order service provision requiring non local trips.

Champion (2002) suggests a combination of urban infill and deconcentrated settlement options rather than the deconcentrated settlement pattern. The main focus is on retaining the distinctive character of existing towns and villages, avoiding large scale extensions which would cause these to merge together. The studies discussed above have modelled a variety of development patterns, assessing their levels of urban sustainability, particularly in terms of the land use/ transport dimension. This establishes that a sustainable development pattern is not necessarily that of the archetypical 'compact city', but can encompass 'decentralized concentration' or polynucleated development patterns, particularly where linkages are established between sub centres.

3.4 Impacts of Urban Sprawl

It is worth examining the impacts or costs of urban sprawl, as the scale at which these occur determines, to some extent, the appropriate scale for measures of urban sprawl. The effects of urban sprawl are one of the most hotly debated issues in the literature, with sprawl often branded as the cause of all the evils of modern urban life. This negative view is richly illustrated by a glance at popular works in the urban literature, titles such as: Fighting Sprawl and City Hall, Divorce Your Car, and Home From Nowhere, illustrate the polemical nature of the discussions. There are a myriad of points made both for the costs and benefits of sprawl. Discussions of these often degenerate into long lists which provide no way to sort through the debates. Despite the volume of rhetoric, the verdict is not yet out on the impacts of sprawl, and it should be viewed in the context of social and urban changes discussed in the section above.

Most studies in the US have focused on measuring the costs of sprawl at the community level (Ewing, 1994, 1997; Ewing et al., 2002; Gordon and Richardson, 1997a, 1997b, 2000; Peiser, 1989; Transportation Research Board, 1998, 2002), despite acknowledgement that most problems directly related to growth are regional not local in nature, particularly with respect to air pollution and traffic congestion (Downs, 1999). Further confusing the issue is the lack of reliable empirical evidence to support the arguments made either for or against sprawl. The summary provided by the Transportation Research Board (1998) lists some of the limitations of the current research on costs of sprawl. This report divides the effects of sprawl into five groups, public and private capital and operating costs, transportation and travel costs, land/natural habitat preservation, quality of life and social issues.

Further issues adding to the poor quality analysis of the costs of sprawl, as summarized by the Transportation Research Board (1998), are the widespread use of secondary data despite the quotation of a wide variety of data sources in the literature. There are unclear definitions of the costs being measured; for instance, density is improperly defined and this makes it difficult to measure travel behaviour or infrastructure costs which are related to the density of a region. There has been a focus on only a few aspects of sprawl, without looking at the causal elements, and few empirical studies and many case studies which are difficult to generalize from have dominated the literature. The benefits of sprawl are often ignored; quantitative analyses are mostly found for physical infrastructure, rather than for social costs or quality of life – when these are some of the most hotly debated issues in the literature. Most discussions focus on the new growth areas, without looking at the impacts on the city core or inner suburbs while the literature looks only at one point in time without examining the effects over a longer time scale. Few feasible alternative forms are proposed as a solution to the negative impacts of sprawl and modelling of the analysis is too simplistic. In general, most findings are either descriptive or where empirical work is carried out, the conclusions vary depending on the viewpoint of the researcher. These critiques point to a need for clearer definitions, more quantitative measures of sprawl, a broader view both in time and space, and greater comparison with alternative urban forms.

The effects of sprawl are too numerous to discuss fully. The following discussion will look at the major debates in the literature as a way of examining the most pressing concerns and to illustrate the problems mentioned above. One way to provide some general organization of the debates is to note that most of the arguments either support urban sprawl or advocate compact development. Those from the planning family usually support compact development and advocate greater regulation and planning to solve the 'problems' of sprawl. The other main champions of the sprawl debate are those who take an economic perspective. In this group, there are both supporters of compact development and of sprawl; however, in both cases the view is that the economic market will ensure efficient development.

The debate on sprawl can therefore be reduced to an older set of arguments, between those advocating a planning approach and those advocating the efficiency of the market. Those supporting planning justify intervention on the grounds that the market is not efficient due to externalities, or unintended effects of actions, the costs of which are not borne by the producer; the existence of public goods which are freely available and therefore not provided by the market; and lack of equity in that the goods and services are not distributed evenly among areas. Those advocating the free market approach assume competitive and efficient markets, point out that actions should be taken to place the cost of externalities on the producer rather than using regulation; and argue that public goods are limited and can be provided by the market itself (Richardson and Gordon, 1993)

3.4.1 *Costs of Sprawl*

In the post war period, despite criticisms of urban growth, suburbanization was seen in a positive light, as a means to provide housing for the burgeoning population of the cities (Self, 1961; Clawson and Hall,1973). At this point in time the impacts of sprawl were less widely discussed than its causes. Tables 3.1 to 3.3 provide a summary of the major costs and benefits of sprawl.

Table 3.1: Costs of sprawl - infrastructure, service and environmental costs (based on Transportation Research Board, 1998)

Cost of Sprawl *(Italics indicate positive impacts)*	Condition Exists	Condition is Strongly Linked to Sprawl
Public/Private Capital and Operating Costs		
Higher infrastructure costs under sprawl than compact development	General agreement	Some agreement
Higher public operating costs	Some agreement	No clear outcome
More expensive private residential and non-residential development costs	Some agreement	No clear outcome
More adverse public fiscal impacts	Some agreement	Some agreement
Lower public operating costs	Some agreement	No clear outcome
Less expensive private residential and non-residential development costs	Some agreement	Some agreement
Fosters efficient infill development	No clear outcome	No clear outcome
Land/Natural Habitat Preservation		
Loss of agricultural land	General agreement	General agreement
Reduced farmland productivity	Some agreement	No clear outcome

Table 3.1 (continued)

Cost of Sprawl *(Italics indicate positive impacts)*	Condition Exists	Condition is Strongly Linked to Sprawl
Reduced farmland viability(Water Constraints)	No clear outcome	No clear outcome
Loss of fragile environmental lands	General agreement	General agreement
Reduced regional open space	General agreement	General agreement
Enhanced personal and public open space	Some agreement	No clear outcome

Table 3.2: Costs of sprawl - transport costs (based on Transportation Research Board, 1998)

Transportation and Travel Costs		
Cost of Sprawl *(Italics indicate positive impacts)*	**Condition Exists**	**Condition is Strongly Linked to Sprawl**
More vehicle miles travelled	General agreement	General agreement
Longer travel times	No clear outcome	No clear outcome
More automobile trips	General agreement	General agreement
Higher household transportation spending	No clear outcome	No clear outcome
Less cost efficient and effective transit	General agreement	Some agreement
Higher social costs of travel	Some agreement	Some agreement
Shorter commuting times	No clear outcome	No clear outcome
Less congestion	General agreement	No clear outcome
Lower governmental costs for transportation	No clear outcome	No clear outcome
Automobile most efficient mode of transportation	General agreement	Some agreement

Table 3.3: Costs of sprawl - quality of life and social costs (based on Transportation Research Board, 1998)

Quality of Life		
Cost of Sprawl *(Italics indicate positive impacts)*	**Condition Exists**	**Condition is Strongly Linked to Sprawl**
Aesthetically displeasing	Some agreement	N o clear outcome
Weakened sense of community	Some agreement	Some agreement
Greater stress	Some agreement	Some agreement
Higher energy consumption	Some agreement	Some agreement
More air pollution	Some agreement	Substantial disagreement
Lessened historic preservation	Some agreement	No clear outcome

Table 3.3 (continued)

Cost of Sprawl *(Italics indicate positive impacts)*	**Condition Exists**	**Condition is Strongly Linked to Sprawl**
Preference for low-density living	General agreement	Some agreement
Lower crime rates	Some agreement	No clear outcome
Enhanced value or reduced costs of public and private goods	Some agreement	No clear outcome
Fosters greater economic well being	Some agreement	Some agreement
Social Issues		
Fosters suburban exclusion	Some agreement	Substantial disagreement
Fosters spatial mismatch	General agreement	Some agreement
Fosters residential segregation	Some agreement	No clear outcome
Worsens fiscal stress	Some agreement	Some agreement
Worsens inner city deterioration	Some agreement	Some agreement
Fosters localized land use decisions	General agreement	Some agreement
Enhanced municipal diversity and choice	General agreement	Some agreement

3.4.2 *Land Speculation*

The first major debate discusses whether land speculation fosters an efficient land market, infill development and therefore higher densities, or whether it contributes to sprawl. This was a major issue in the literature of the 1960's and 1970's reflecting the emphasis on causes of sprawl rather than costs, the literature also emphasizing reasons for discontinuous/scattered development rather than suburbanization. It also interestingly examines the influence of individual actors which is not common in more recent literature. This issue brings to the fore the need to look at sprawl over longer periods of time.

The first issue is whether land speculation is part of an efficient land market. Under traditional theories of the land market, the expected pattern of development would be continuous development from the urban centre. Efficient development would first make use of the land closest to the centre, as this is the highest value, is the most accessible and utilizes existing public services. Discontinuous, scattered development can therefore be seen as a result of market failure. On the other side of the debate scattered development is seen as part of an efficient land market which provides the highest price for land owners, and allows for appropriate provision of infrastructure and services.

Land speculation is seen as the cause of discontinuous development, at least in the short term (Archer, 1973; Ottensmann, 1977). The process as described by Clawson (1962) is one in which land is withdrawn from the land market and its price is placed above its current market value in anticipation of future demand for higher value urban uses. The time at which the particular parcel is released onto the market depends on the rate of development of surrounding tracts, the availability of capital to the speculator, and the cost of holding land in taxes. When demand is high and profits are greater, then more land parcels will come onto the market. Due to individual differences in parcel characteristics and land owners individual preferences, land development is haphazard, leading to scattered development. The withheld land is often vacant since land cannot be used for other purposes, such as farming, as it is necessary to maintain flexibility of use so that the parcel is available for sale when prices are high.

On the other hand, over a longer time period, land speculation creates an efficient allocation of land uses. Although initial development is low density, the vacant land is later developed at higher densities as infill development or is used for higher value commercial uses. This is dependent on land owners allocating a high price for land based on its prospective value in the future. Land is therefore not developed under existing lower value uses, but only when the more productive uses are economically feasible (Harvey and Clark, 1965; Ohls and Pines, 1975; Peiser, 1989). It is well established in the literature that density of development increases with land value. This assumes that land values on infill sites will be higher than land at the urban fringe, although this is not always the case due to zoning restrictions and decline of the inner cities, and ignores the question of overall density. Development will continue at the urban fringe, even as higher density infill development occurs, as fringe land will continue to be attractive (Breslaw,1990)

Although the issue of land speculation is not discussed in the current literature, it provides some understanding of the working of the land market, highlights the causes of scattered development rather than suburbanization and points to the need to look at the whole cycle of development in an area, not just at its inception but also at build out. Further questions for study are the role of land use policies in controlling speculation and subsequent scattered development, the timing of this infill development, that is how long it takes for these higher density uses to emerge, the necessary conditions for this, and the effect this has on the overall density of development in the region.

3.4.3 *Costs of Sprawl - Gordon and Richardson versus Ewing*

The second debate which returns to the costs of sprawl is essentially one between advocates of a compact city form with development control through planning (Ewing,1997) and those supporting the dispersed pattern of development with market led development (Gordon and Richardson,1997a; 1997b).

Gordon and Richardson look at several costs of sprawl: lack of open space and use of agricultural land, low density residential development as caused by income tax breaks and subsidies to the automobile and highway, wasteful use of energy, lack of public transit, traffic congestion and trip times, the decline of the downtowns, and residential segregation between suburbs and inner cities.

They do not attempt to claim that these costs are non existent, merely that they do not hamper efficient development at higher densities, or are not caused by urban sprawl. For instance, Gordon and Richardson concede that low density development makes public transit unfeasible; however, they also claim that ridership is in decline despite increases in public subsidies and that more compact development in the form of New Urbanist neighbourhoods does not make a difference in transit use. Another claim is that suburbanization has not increased congestion, and that commuting trip times of central city and suburban residents are similar, due to the movement of industry to the suburbs; a third claim is that infrastructure costs savings at higher densities are small.

Despite the impact of this debate, Gordon and Richardson do not provide any empirical analysis to support their claims, and rely on secondary evidence. Underlying the refutations of sprawl's costs is a perception of city form as a more dispersed polycentric city not as emanating from a central core,

> " the central city vs. the suburbs is yesterday's battle. Even "edge cities" are becoming old news. Today's contest, ...is between the suburbs and the exurbs." (Gordon and Richardson, 1997b, p.277)

The counterpoint by Ewing (1997) shares similar deficiencies in empirical evidence, and contains an implicit assumption of the ideal city as a compact form surrounding a central core. He attempts to refute each of the arguments of Gordon and Richardson. However, while it is established that the negative impacts exist, he does not manage to tie these directly to sprawl as a causal factor. Many of the costs mentioned are just the costs of modern urban living, regardless of urban form. Ewing rightly points out that Gordon and Richardson do not provide a clear definition of sprawl, but he does not address the influence of definition on their relative findings. Additionally, much of the disagreement on the costs of sprawl is due to the lack of empirical evidence, and the comparison of costs based on different methods of measurement. For instance, when discussing the level of congestion in sprawl communities, Gordon and Richardson quote travel times of 18.2 minutes for central city residents in urbanized areas and 20.8 minutes for those outside central cities for all modes of travel. Ewing finds trip times of 40 minutes less for those in most accessible locations over those in least accessible locations, using auto trips only. The main discrepancies are in the definition of the comparison areas – Gordon and Richardson base this on density, while Ewing uses accessibility; and the modes of travel measured – all modes versus auto trips. Further confusion is added by the use of secondary data; indeed Ewing does not cite any source of data.

3.4.4 Costs of Sprawl – Gordon and Richardson versus Pendall

The debate between Gordon and Richardson (1997a) and Pendall (1999) on consumer preference for low density living further illustrates the methodological problems plaguing the costs of sprawl literature. Pendall attempts to refute Gordon and Richardson's claim that consumer preference leads to low density development. Instead he aims to show that land use controls and fiscal arrangements can influence density. The implication is that the market is flawed and that policy intervention can create higher density development. Gordon and Richardson quote consumer preference surveys, for example, the Federal Home Mortgage Association's National Housing Survey, as evidence of a desire for low density living. On the supply side, they claim that even where higher density development is allowed, developers do not build at higher densities and that sales of higher density development are slow. However, no empirical studies are used and no literature is cited. Pendall uses OLS regression to test seven factors which influence density, with findings that land use controls have a significant impact. From this he concludes that government actions can be more important than consumer preference on densities and spatial patterns. However, the argument is very indirect, and although it establishes a causal relationship between land use control and density, it ignores the issue of consumer preference and the workings of the land market. Once again data is flawed or missing, and empirical studies while of sound methodology do not directly measure the cost of sprawl, and perhaps stretch too far in their conclusions.

3.4.5 Municipal Fragmentation

One factor which deserves some mention as exacerbating the costs of sprawl is municipal fragmentation. This is a problem for the US where regional government is weak, and control over land use falls to local municipal authorities. Planning is therefore uncoordinated and fragmented. Policies to prevent sprawl therefore have little effect, as they are uncoordinated and not implemented over a wide enough area (Clawson, 1962; Razin and Rosentraub, 2000)

3.4.6 Transportation

Another major issue is the transport related costs of sprawl. In terms of vehicle miles travelled (VMT), sprawl is seen to generate more miles of vehicle travel than more compact forms of development. VMT in the US has increased at over 3 percent per year during the 1980's and is forecast to increase another 25 percent per capita between 1990 and 2010 (Holtzclaw, 1994). For example, a study of 28 neighbourhoods in California linking lower VMT with more compact mixed developments have found that residents of denser neighbourhoods drove fewer miles per year, and controlling for levels of transit service and vehicle ownership doubling residential densities resulted in 16 percent fewer VMT (Holtzclaw, 1994).

For example, with respect to transport, congestion is seen as the main cost of sprawl at the local and individual level. This cost is deemed to be acceptable at the community level, as individuals desire a wide range of choices to live and work, want multi purpose trips, to live in low density communities, to travel by private car and to live in segregated areas. Given these individual choices, congestion is seen as an acceptable trade-off (Downs, 1999). This focus on the impacts of sprawl to the individual result in an examination of a narrow geographical area, with measures of sprawl tailored to this scale. Segregation of uses has also been found to increase VMT in a study of dispersed sub centres in the San Francisco Bay area. Between 1980 and 1990, the workers at these subcentres experienced a 23 percent increase in average commuting VMT, with 80 percent of the increase due to longer distances between home and work (Cervero and Wu, 1997).

Sprawl is also claimed to result in longer travel times than compact development, as the greater dispersion of activities results in more time spent travelling between activities than in compact activities where trips are shorter and often multi purpose. Ewing (1995) has found that total travel time varies with regional accessibility. His study of Florida found that residents of areas with high levels of access to a mix of uses spend up to 40 minutes less per day in vehicular travel than residents in less accessible neighbourhoods. Time is saved by linking trips and by making shorter trips. Others argue that travel times do not increase with sprawl as more trips are made by automobile which is faster and that people adjust trips to keep travel times constant (Gordon and Richardson, 1997a). On a metropolitan scale, data suggests that people have fairly constant travel time budgets. However at a neighbourhood scale, the segregation of uses has increased the amount of time households spent travelling to their daily activities (Transportation Research Board, 1998).

It is also claimed that sprawl results in higher numbers of automobile trips, due to low densities and increased spatial segregation. More compact development results in an increase in transit and walking mode shares and a decrease in vehicle mode shares. Higher residential developments in rail corridors and higher employment densities in the CBD result in increased rail travel (Parsons Brinckerhoof Quade and Douglas Inc., 1996a). Kenworthy and Newman (1993) compare rates of growth in central, inner and outer neighbourhoods in the United States and Australia, and conclude that automobile travel was growing rapidly in the outer areas of cities in both countries. This is interesting as the wealthy move to the suburbs in the United States while those in low income move to the suburbs in Australia, so automobile use independent of wealth increases as population moves to lower density areas (Kenworthy and Newman, 1993).

Sprawl also results in less cost efficient and effective transit, due to the dispersion of origins and destinations. Denser areas result in higher ridership with more cost efficiency and effectiveness. Light rail and commuter rail use increase when people live in the rail corridor and work in the central city. At the community and societal levels, impacts of sprawl such as air pollution and energy costs come into play (Newman and Kenworthy, 1988, 1989, 1999). For instance, examination of the relationship between urban densities, journey to work distances and use of public transport, concludes that urban density is the only variable that varies systematically with gasoline consumption. Cities with high densities also have low car usage and high levels of public transport. In American cities, there was a negative relationship between average work trip length and consumption, so as trip length increases, gasoline consumption decreases. This was also the case in cities with strong sub centres such as Toronto. The studies focus on work trips to the CBD remaining the major focus of transport patterns (Gordon and Richardson, 1997a; Kenworthy and Laube, 1999; Newman and Kenworthy, 1989, 1999). Gordon and Richardson, on the other hand, claim that in the US commuting times and distances have fallen due to employment decentralization, suburb to suburb commuting, and an increase in non work trips.

The geographical area of interest in each instance is tied to the costs of sprawl, with most studies focusing on the metropolitan region. The European literature focuses on a wider metropolitan or regional scale of impact with the US literature focusing on the costs to the individual and the community. Measures of sprawl applied to US cities have typically focused on the city wide scale, reflecting this more individualistic view of urban sprawl. However, measures of the spatial patterns of urban sprawl have focused on the urban area both in studies of the UK and US.

3.5 Summary

A working definition of sprawl is both country and time specific, and secondly, it is necessary to see sprawl as a normative concept, set against the policy and planning goals for cities. This is an important point to note as sprawl in the United States differs in form, characteristics and consequences from that in the UK and Europe. As a result current work on measures of sprawl derived from US concepts are not necessarily suited to the European. This study views urban sprawl in the context of urban sustainability, and within the context of a polycentric development pattern, rather than the focus on the more immediate urban area.

Definitions of urban sprawl have typically focused on the local area, as this term has been rooted in the US experience, in which interest in urban sprawl and its impacts lie at the neighbourhood and individual level. Application of measures of sprawl to the European context benefits from viewing this phenomena in terms of the wider concern over urban sustainability, and as the flip side to the compact city urban form. This too has traditionally assumed a monocentric urban form, with studies focusing on the urban area. However, studies of sustainable settlement patterns show that it is important to view this in the context of the wider metropolitan or regional scale, with measures of sprawl taking into account levels of sprawl among deconcentrated settlement patterns.

Chapter 4

The SCATTER Project

4.1 Overview of the Project

This section discusses the results of the qualitative assessment of urban sprawl in the case cities of the SCATTER project provided through literature review and a series of interviews with experts in the case cities. The SCATTER (Sprawling Cities And TransporT from Evaluation to Recommendations) project provides an analysis of urban sprawl in Europe, examining the definition of sprawl in a European context, and modelling the relationship between transport infrastructure and urban growth through various case cities. The results of the analysis were used to develop recommendations for tackling and monitoring sprawl in Europe. The project was conducted by the Centre for Advanced Spatial Analysis, University College London, together with six other partners: STRATEC, STASA (Steinbeis Transfer Centre Applied System Analysis), LT Consultants, CERTU (Centre for Studies on Urban Planning, Transport, Utilities and Public Construction) , and TRT (Transporti e Territorio Srl) as part of the European Commission DG Research under the 5th Framework Programme (Thematic Programme 'Energy Environment and Sustainable Development' and Key Action 4 'City of Tomorrow and Sustainable Development'). The project is also part of the LUTR (Land Use and Transport Research) cluster which links several different projects in the area of sustainable urban mobility, including land use, transportation, and the environment. The work consists of three parts, with the first part developing a definition of urban sprawl in Europe and providing a review of possible impacts of urban sprawl. This was conducted through literature review and a series of interviews with experts in the case cities.

The interviews investigated the level of local authority awareness of urban sprawl and related problems, along with measures being used to tackle sprawl. The theoretical review of sprawl provides a context for the more localized interpretation of sprawl from the local authorities and experts in the case cities.

The statistical analysis of urban sprawl forms the second section of the project, which looked at the pattern of sprawl over a 30 year period. The interpretation of sprawl is based on population and employment densities, and patterns of concentration of development. The third section of the project sets up recommendations for sprawl in European cities and presents methods of monitoring sprawl. The analysis revealed a complex pattern of sprawl in the case cities and although it was clear that the extremes of urban sprawl described in the US literature were not evident, it was not possible to identify a clear definition of sprawl in the case cities. The case cities displayed a combination of types of sprawl, often with similar land use impacts regardless of urban form. Sprawl and its results are also clearly influenced by processes operating at a variety of scales - from the context set by national migration and economic strategies to the specifics of local history and culture. This is contrary to the literature which suggests a clear typology of sprawl and associated land use impacts.

The case studies were selected before the project began in that the partners negotiated with one another and focussed on cases that they themselves had prior knowledge of. Only in the case of CASA, the centre in which this PhD research was conducted, was the case study (for Bristol) chosen with regard to the best one in southern Britain as an example of urban sprawl. All the other cases - Brussels, Stuttgart, Helsinki, Milan and Rennes were based on existing work and local knowledge of the other partners. This section examines the identification of sprawl by local government officials and experts in the case cities.

4.2 Background to Interviews in the Case Cities

A series of semi structured interviews were carried out for each case city, with a selection of local experts from city and regional bodies. These included urban planners, regional planners, transport planners, local government officials, and academics from the case cities. The number of interviews for each case city were five interviews in Helsinki, six in Milan, three in Stuttgart, six in Rennes, four in Brussels and five in Bristol – the interviews are not meant to provide a statistical sample but to provide an in-depth discussion of opinions on the nature of urban sprawl, its characteristics, causes and consequences, as well as local policies in place to tackle sprawl. These were supplemented by analysis of local plans and other planning documents. The questions used as a basis for the interviews are listed in Table 4.1.

4.2.1 Questions for the Semi Structured Interview

The interviews for the case studies were carried out between August and September 2002 by the SCATTER partners. Each SCATTER partner was responsible for conducting the interviews in the relevant case city, and for translation of the interviews. The subsequent analysis was conducted at CASA. The interviews for the Bristol case study were conducted by CASA. The selection of interviewees covered experience of urban sprawl at a variety of scales - local, metropolitan and regional - and of differing aspects of sprawl, including planning and transport experts, municipal politicians and also academic experts. Interviews lasted for one to two hours and allowed for exploratory discussions of urban sprawl, with the interview questions used primarily as a guide to ensure a comparative coverage of topics across the case cities.

Table 4.1: Questions for SCATTER case study interviews

<u>*A. Urban Growth*</u>

1. Can you tell me the brief history (10 years or so) of urban growth in the city of xxx?
2. Can you describe which have been the major 'spontaneous' changes in the city? (Probe: structure, spatial distribution of activities, of residence, of jobs, of population, commuting, transportation network)
3. How would you describe the current spatial structure of the city and surrounding region? (Probes: scattered, leapfrog, linear, edge cities)
4. How would you describe the current land–use structure of the city and surrounding region? (Probes: mixed, segregated, (commercial or residential poles, mismatched)?
5. (Showing a map of the study region) Can you comment on the information displayed according to statistical data on population, built-up areas, other?
6. Why do you think these (land-use, spatial) structures have emerged? (Probes: have they been planned; other probes in Table 1.)
7. If you had to describe what urban sprawl means to you, what would you say? Prompt: What words come to mind? What images?
8. What do you think about urban sprawl in general? (Prompts: social segregation effect, environmental effects, mobility effects)
9. What do you think about urban sprawl with regards to the city xxx and its surroundings?

<u>*B. Identity Impacts*</u>

1. Can you describe the major problems/ advantages that such changes have brought to the city of xxx ? (Probe: environment, traffic, economic costs, financial costs, welfare. See Table 2 for other probes)
2. How has the commuting changed in relation to urban growth? (Probe: intensity, origin/destination, reasons, modal split).

<u>*C. Implemented Measures*</u>

1. Can you briefly describe the planning, land-use and transport policies or plans currently implemented or about to be implemented in the city of xxx ? (Probes: purposes of the plan / policy, which are the responsible regional, local authorities, quangos; which is the spatial extent of this policies, when were these policies implemented)
2. Would you like to mention any other policies or plans that have been or will be implemented and which you think might affect the structure and functioning of the city?
3. What do you think have been the main reasons to launch these policies?
4. What can you tell us about the decision-making processes involved in the design and implementation of these plans/policies? (Probes: who(individuals, institutions) was involved, when was the subject brought out)
5. Which have been the results of the implemented policies so far? (Probe: side effects, correspondence between expected and actual results)
6. Have there been barriers or difficulties in implementing these policies/plans? (Probe: fragmentation of governance among several authorities, resistance from public, private, third parties, mismatch with other existing public policies/ plans?
7. Which suggestions do you have to improve these policies?
8. Do you have any other suggestion on what the city of xxx should do to plan its future? (Probe: sector policies, change in administrative structure, improve knowledge on spatial and land use structure)
9. One of the objectives of the SCATTER project is to design a monitoring tool addressed to local authorities, to monitor the evolution of sprawl and its effects. Practically, it will consist in a list of relevant indicators. What is your view on such a tool? (Probe: usability, integration with other tools, suggestions on indicators or variables).

Table 4.1 (continued)

Table 1: List of probes for question A.3
Explanation of sprawl emergence
Housing markets (housing prices lower in the periphery than in the core city)
Appeal of a rural ambiance
Appeal of a low density settlements
Decrease of travel times and costs due to the extension of the highway network
Decrease of travel times and costs due to the improvements of public transport services (heavy rail, light rail) serving the suburban area and linking it to the city centre
Rejection of the core city due to damaged buildings, dirtiness, car traffic, lack of safety due to traffic, noise, air pollution
Rejection of the core city due to congestion
Rejection of the core city due to social problems
Development of economic poles in the outer urban area or delocalisation of companies from the core city to the outer area
Economic Causes
Restructuring and relocation
Emergence of SME and decline of large enterprises
Development of an economic pole in the outer urban area
The growth of employment in particular localised industries like mining, defence and tourism
The restructuring of manufacturing industry and the associated growth of branch plants
The growth of employment in the public sector and personal services
The effect of economic recession on rural-urban and return migration
The first round in a new cyclic pattern of capital investment in property and business?
Demographic
Increase of the total population of the city
Inherent changing in structure population
The expansion of commuting fields around employment centres
The concentration of rural population into local urban centres
The reduction of the stock of potential out-migrants living in rural areas
The acceleration of retirement migration
Change in age structure and household size and composition
Social
Increase of household income
The emergence of scale diseconomies and social problems in large cities
The improvement of education, health and other infrastructure in rural areas
The change in residential preferences of working age people and entrepreneurs.
Institutional/Political
The availability of government subsidies for rural activities
The success of explicitly spatial government policies, if yes which ones
The growth of state welfare payments, private pensions and other benefits
Transport related events
Improvements in transport technology
Improvement of sub-urban public transport service
Improvement of sub-urban road infrastructure
Application of specific transport measure, if yes which one

Table 4.1 (continued)

Table 2: List of probes for effects of sprawl
Public/Private Capital and Operating Costs
Infrastructure costs
Private residential and non-residential development costs
Public fiscal impacts
Transportation and Travel Costs
Vehicle/miles travelled
Travel and commuting times
Private vs public transport
Household transportation spending
Congestion
Public costs for transportation
Land/Natural Habitat Preservation
Agricultural land
Farmland productivity
Farmland viability (water constraints)
Open space
Quality of life
Aesthetic issues
Sense of community
Energy consumption
Air pollution
Crime rates
Costs of public and private goods and services

4.2.2 *The Case Cities*

The study regions for the project were selected using the definitions described in Table 4.2. Each area is divided into three zones – the urban centre, the outer urban ring and the hinterland, shown in Figure 4.2. The urban centre was defined by the administrative boundaries of the case cities; for example, the Bristol urban centre is defined by boundaries of the local authority district. The outer urban ring was defined in most cases as a functional area which is tied to the urban centre through commuting ties. In the case of Helsinki, the outer urban ring was defined by the political boundaries of the Helsinki Metropolitan area, however there are strong economic ties to the urban centre. The hinterland was defined as the area with fewer ties to the urban centre, although there exist some exchanges with the urban centre.

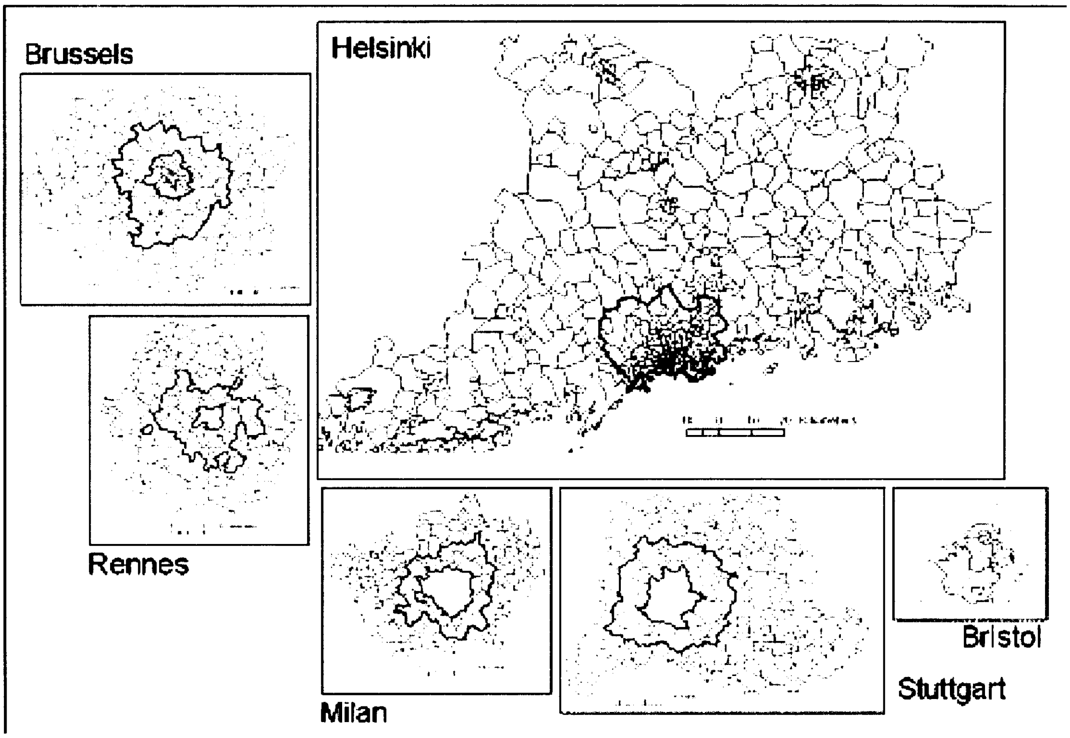

Figure 4.1: Study area of the case cities of Brussels, Rennes, Milan, Bristol, Stuttgart and Helsinki

The scale used for each case city varies but scales are functionally similar as they are based on similar commuting patterns or functional ties to the urban centre. These cities were selected as they are facing situations of population and economic growth, within planning contexts of varying strengths.

Table 4.2: Population and areas of the case cities

City	Population	Size km²	Urban Centre	Outer Urban Ring	Hinterland
Bristol	931,531	1,346 km²	City of Bristol (92 km²)	Wards with >40% if workers commuting to centre (386 km²)	Wards with <40% commuting to urban centre (868 km²)
Brussels	3,913,795	4,495 km²	Capital Region (164 km²)	Urban suburban ring described in the Regional Mobility Plan 1991-1996 (1080 km²)	Rest of functional urban area (3552 km²)
Helsinki	1,892,488	16,024 km²	City Centre (63 km²)	Helsinki Metropolitan Area – political administrative area (1321 km²)	Rest of Helsinki commuter area (14640 km²

Table 4.2 (continued)

City	Population	Size km^2	Urban Centre	Outer Urban Ring	Hinterland
Milan	3,606,926	1,966 km^2	City of Milan (180 km^2)	Functional urban area tied to Milan in terms of similarity of policy issues such as traffic bans and included in other research on transport and environment (450 km^2)	Rest of Milan province (1336km^2)
Rennes	521,188	2,542 km^2	City of Rennes (50 km^2)	La Communaute d'agglomeration political area (559 km^2)	Rest of functional urban area (1933 km^2)
Stuttgart	2,613,379	3,653 km^2	City of Stuttgart (207 km^2)	< 17km commuting distance from city centre (759 km^2)	Rest of Stuttgart urban region (2687 km^2)

The details of the zones for each study region are as follows. For the case cities of Brussels and Milan, the three zones defined for the SCATTER project did not conform to the functional areas previously observed in these cities. In the case of Brussels interaction with the urban centre is strongly influenced by growth poles within the study area, and in Milan development takes the form of a pattern of radial growth from the city centre, which results in an urban form which does not reflect the concentric structure of the zones used for the SCATTER project. This alternative functional division is therefore shown in Figures 4.3 and 4.4.

In the Brussels case city the urban centre has been defined as the Brussels-Capital Region, the outer ring contains its suburbs and the hinterland contains the territories of the Flemish (north) and of the Walloon Regions (south), along with secondary cities (such as Aalst, Leuven, Mechelen, Louvain-la-Neuve), which are more autonomous from Brussels, shown in Figure 4.2. There are also cities just outside the study area, such as Antwerp or Liège (economic poles), which have strong economic functions, these generate strong exchanges with some parts of the study area but are not included in the study area.

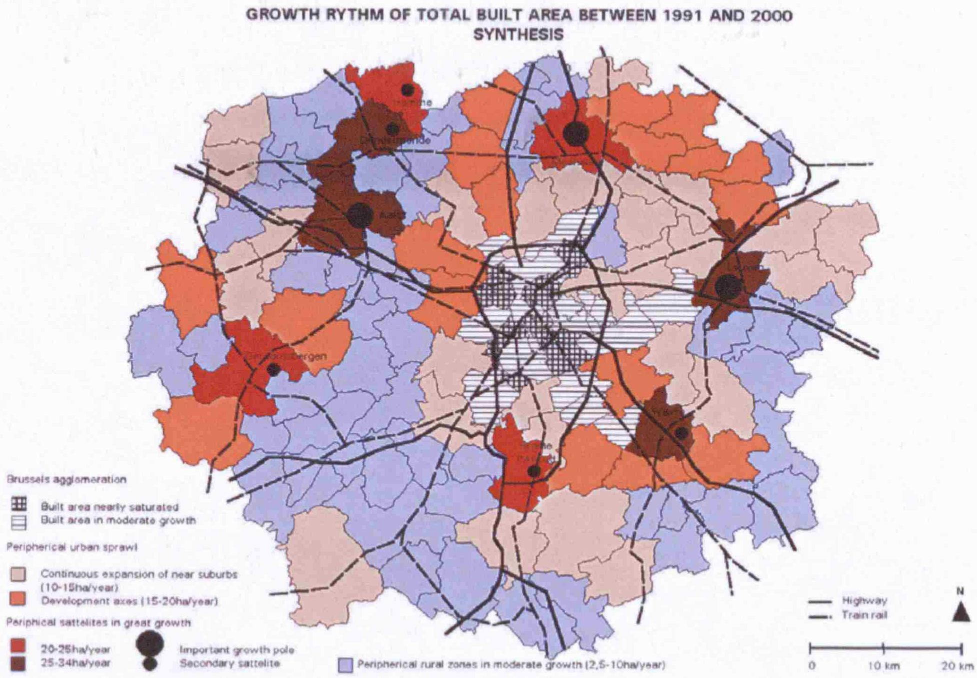

Figure 4.2: Secondary growth poles in Brussels study area

The Milan case city study area corresponds to the administrative unit of the province of Milan. The urban centre comprises the city of Milan, the outer ring consists of the Milan Metropolitan area, and the remainder of the province is located in the hinterland. It should be noted that this concentric division of the study area does not correspond to the arrangement of the municipalities in Milan, which can be grouped into homogenous zones, namely the north zone (the main municipalities are Sesto Brianza), the east zone (Vimercate Adda), the south zone (mainly rural), the west zone (Magenta Abbiategrasso) and the northwest zone (Rho Legnano) as shown in Figure 4.3. Patterns of growth tend to occur within these 'development corridors' – therefore the statistical analysis of urban sprawl, being based on a concentric structure, may not reflect the patterns of growth identified by those within the region as described in the interviews.

Figure 4.3: Municipalities of Milan

The Helsinki case city covers the city of Helsinki in the urban centre, in the outer urban ring a metropolitan area with the three other neighbouring cities, Espoo, Kauniainen and Vantaa. The hinterland covers the other parts of the Province of Southern Finland as well as the largest neighbouring towns of Lahti and Hameenlinna. It is the largest study area but this is due to the fact that the metropolitan area has a strong influence over its rural hinterland, and is expanding in its function as an employment centre serving the surrounding region.

The Rennes case city study region is based on a statistical level termed the *aire urbaine.* It is defined by the French national statistics institute (INSEE) as a functional urban area delimited from analyses of commuters trips after each census. In this study, the limits are derived from the results of the analyses of the commuters trips in 1999. An *aire urbaine* comprises several local-authority areas (communes) where 40 percent of the inhabitants work in the city centre.

The Rennes 'urban centre' comprises the commune of Rennes in the urban centre. The 'outer urban ring' includes the local authorities which together with the central city form an administrative body called the *Rennes Métropole*. This institution was created in 1974 and has implemented several policies for urban planning, transport, environment, housing. The "hinterland" includes all other communes of Rennes "*aire urbaine*" but outside the *Rennes métropole*.

The case city of Stuttgart covers the whole of the Stuttgart region and is situated in the south-west of Germany. The outer urban ring consists of the neighbouring districts Boeblingen, the Rems-Murr-Kreis, Ludwigsburg, Esslingen, and Goeppingen, with the hinterland consisting of the rest of the region.

The Bristol case city covers the former county of Avon, with the urban centre comprising the local authority district of Bristol. The outer ring and hinterland are defined by commuting zones towards Bristol. As with the Milan case city, development in Bristol does not occur strictly in a concentric pattern. The secondary poles of Bath and Weston-super-Mare create some distortion, and although Bristol remains the main focus of growth, a series of concentric rings around each of the poles can be identified. It should be noted that the outer urban ring is not contiguous due to variations in commuting patterns.

The land cover maps in Figure 4.4 provide some context for the analysis in each region. These are from the Corine 1990 land cover data at 100m resolution, and are based on data collected at 1:100,000 map scale with a minimum mapping unit of 25 hectares (.25 km^2). The cities of Helsinki and Rennes can be seen as the main urban areas in a rural and agricultural hinterland. In Milan and Brussels the polycentric patterns and extensive linkages between main and sub cities is evident. Bristol and Stuttgart show a rather more amorphous urban form, although development in Stuttgart is spread across the region.

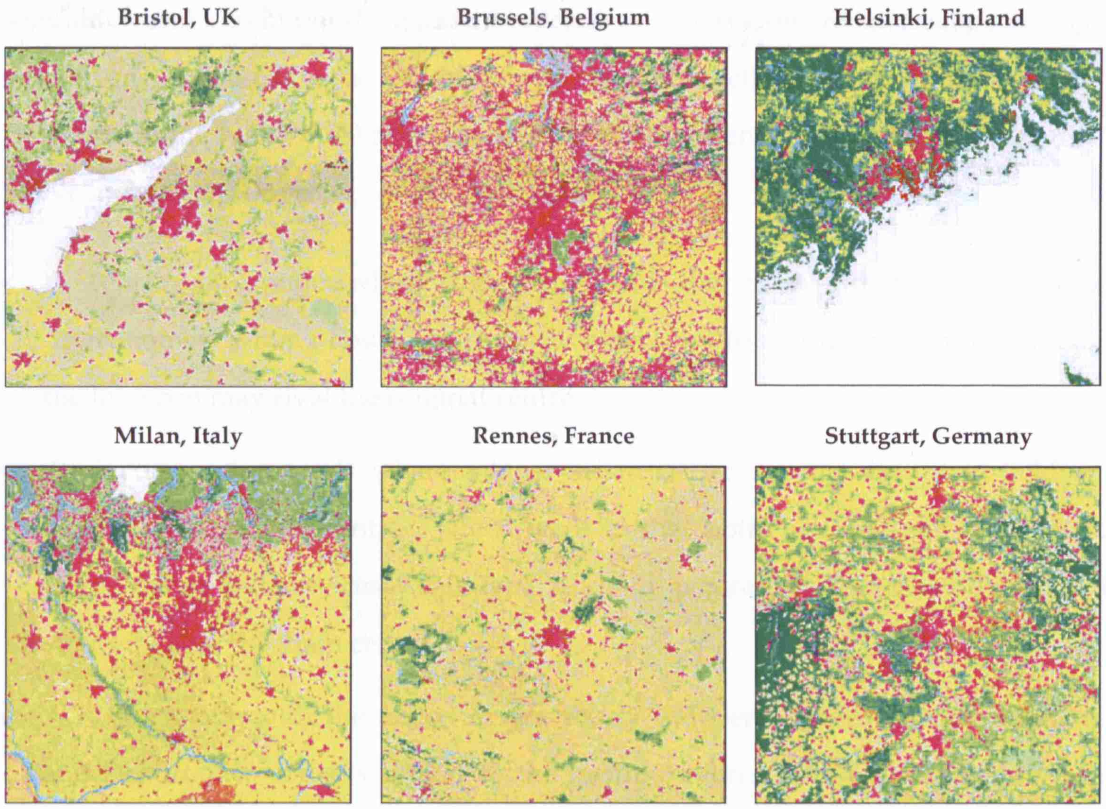

Figure 4.4: Urban land use (purple) from remotely sensed data (Corine 1990) in the six SCATTER case cities

4.3 Typologies of Sprawl

The SCATTER project develops four theoretical typologies of sprawl in Europe (CASA et al., 2002) derived from work by Champion (2001) and Camagni et al. (2002). The profiles comprise a description of their spatial and functional structure, the most relevant impacts and an outline of the policies that either have been implemented or have been suggested by the interviewees to mitigate and control the problems connected to each typology. Nevertheless, the nature of sprawl in the case cities does not conform to any one particular typology, but rather consists of a mixture of sprawl forms and impacts which in some cases is unique to the European situation but in others also encompass issues relevant to the concerns of sprawl in United States.

4.3.1 Emergent Polycentric Region

The polycentric urban region is characteristic of sprawl at a regional scale. This is characterised by the presence of secondary urban centres formed by the migration of population and jobs out of the main urban centre of the region. Relationships among centres can vary according to degree of intensity and functional specialisation, and by the nature of the functional links between centres. Polycentric urban regions can evolve in different ways:

- A centrifugal mode where the growth of the main urban centre creates diseconomies forcing housing and employment out to alternative centres which in the long run may rival the original centre.
- An incorporation mode where a large urban centre expands its urban field and incorporates smaller centres, which were to that point self-sufficient in terms of employment and services. This type tends to generate further economic growth strengthening the main centre.
- A fusion mode with the fusion of previously independent centres of similar size and importance. This is similar to the incorporation mode, but in this event the secondary centres retain some autonomy from the main urban centre. The improvement of transport links plays a major role in this mode.

The main negative impact is an increase in levels of travel, particularly on transport infrastructure leading towards the main urban centre. Congestion on radial routes, rings of traffic jams and reduced accessibility to the central areas have been identified. In these areas transport policies which increase the supply of infrastructure, have increased the level of urban sprawl, by enabling higher levels of travel, increasing trip lengths and congestion. In some cases there is a short term reduction in congestion, however, the long term impacts result in further waves of sprawl.

Mobility remains focused on a few specific origin / destination patterns and there is a highly developed transport infrastructure between places. This makes it possible for public transport to reach a feasible density – policy measures tackling sprawl in these areas therefore often focus on reducing trips by private car, using measures such as road-pricing, parking fees, congestion charges and taxes on CO^2 emissions. Positive impacts of sprawl include the redistribution of population and employment promoting development in small and medium size cities, which can offer a better quality of the environment, and better local public services such as schools and health centres.

4.3.2 *Scattered Suburb*

This typology of urban sprawl is characterised by the development of scattered and low density housing developments between urban centres or between transport infrastructures. There is high quality housing and residential environment but the supply of public services is limited, and consists primarily of commercial centres similar to the American suburbs. The impacts of sprawl are mainly due to the scattered and low-density nature of these developments.

Transport is characterised by the private car because of the high number of origins and destinations of trips which makes it impossible to reach the feasibility threshold for public transport. Moreover the low density of these developments generates high levels of land consumption both for housing and infrastructures and higher urbanisation costs.This type of sprawl is perceived as lacking a sense of community and of urban identity. Nevertheless, the residential suburbs are the choice of location for the majority of young families with children who have a medium to high income. Solutions are mainly directed at promoting more compact and mixed land-use development. Policies aim to promote a more strategic and coordinated set of land-use and transport plans, through the enforcement of building regulations, and fiscal measures which promote denser developments.

4.3.3 *Peripheral Fringes*

The sprawl of peripheral fringes is created by the movement of low income and immigrant groups who have no choice but to relocate because of the increasing costs of life in the urban centre. These groups consist of illegal immigrants, students, and retirees who cannot afford the residential suburbs described above.

Peripheral fringes occur in the less desirable land areas where costs are cheaper : either beyond the residential suburbs or in other cases as a substitute for the residential suburb. The peripheral fringe often occurs closer to the centre when accessibility to the centre is limited. These occur not only round the main urban centre but also around the secondary centres.

Housing is characterized by old public housing built in the 1950s or 1960s, and by poorly designed private sector housing, built by speculative developers. Densities are higher than the scattered suburban developments. Negative impacts are an increasing level of social deprivation or segregation and degradation of the built environment. Possible solutions are regeneration programmes focused on peripheral areas rather than on the central areas of the main and secondary centres. In several cases, regeneration plans have also exploited an improved concern with regards to the coordination of land-use and transport planning at the neighbourhood scale.

4.3.4 Commercial Strips and Business Centres

Another form of urban sprawl is the development of commercial, service and business centres outside the boundaries of the compact city. These developments reflect the result of a planning approach that sees land-uses as mutually competitive and produce a system of market forces, which play a critical role in determining land price mechanisms. The location of these land-use functions is based on accessibility, low cost of land and agglomeration economies. As a result these activities locate close to transport infrastructure, for example airports, ports, and motorway junctions. Negative impacts are high levels of mobility served by private transport. High levels of land consumption are also present, as planning control is often weak in these areas. Solutions include planning and fiscal measures to control the demand and supply of development areas.

4.4 Perceptions of Urban Sprawl in the Case Cities of Brussels, Milan, Rennes, Helsinki and Stuttgart

In the Brussels Capital region, urban sprawl is seen as *the* major urban problem, and is defined as a movement from the urban centre to the suburbs. To some extent the perception of sprawl as positive or negative depends on the flow of benefits between main and secondary cities. For example, in Waterloo, a peripheral centre in the Walloon region, which has attracted a wealthy population, sprawl is seen in quite a positive light. However, according to an official in the Spatial Planning Section of the Ministry for the Flemish Community *'the spatial structure of Brussels became, since the 1960s, quite representative of the middle type of American town'.*

Residential densities are similar to the American city, with an exponential decrease in density from the centre to the suburbs, leaving apart the central business district (CBD) which consists of a 'density crater'. The urban centre however shows a greater socio-economic mix than the typical American city. Poorer neighbourhoods cluster around the old south west – north east industrial axis which runs though the city, but this alternates with middle and high income neighbourhoods around the axis. In a phenomenon peculiar to Europe, there is a concentration of migrants in the city centre – in Brussels consisting of Arabic – Muslim and African groups of people - particularly around the train stations. Although deprived groups are present, their location in the centre and the mixture of income groups, does not match the idea of the sprawl of the peripheral fringe.

Unlike sprawl in the US, retail and commercial activity remain strong in the urban centre – primarily due to the situation of Brussels as a focus for financial and tertiary services. Two main centres exist – the Quartier Leopold and the Quartier Nord, and retail service remain strong in Brussels. The existence and strength of the Quartier Leopold is perceived as evidence of the strength of public sector intervention, having been built as a public sector project under the ABC policy which locates offices near to public transport, charges development impact fees to developers, and restricts the type of developments possible. The ABC policy, first developed in the Netherlands, integrates land use and transport. It aims to create a match between the "mobility profiles" of the companies, defined by number of employees and visitors, dependency on car traffic and freight traffic, and the "accessibility profiles" of the locations, defined by access to public transport, access to motorways and levels of parking. The profiles are defined by three major categories - A, B and C. The A-type companies are those which have a high concentration of employment, and a large number of visitors, whose activities are not very dependent on access by road. These should be located in A-type sites which are sites with high-quality access by public transport, poor access by car and limited availability of parking. The C-type companies which have a low concentration of jobs, small number of visitors, activities which are heavily dependent on access by road. These should be located in C-type sites, with good access to motorways for transport by car or lorry. The B type companies and areas have characteristics in between those of A and C. This strength of the planning sector is seen as a major reason for the continued vibrancy of the Brussels urban centre and reducing the negative impacts of urban sprawl.

Another characteristic of sprawl, common to all the case cities, is the movement of middle income couples with children to the suburbs (outer urban ring). In a phenomenon repeated in the other case cities, the city centre is seen as the desired location, but high land rents force a movement out to more affordable locations, yet with good quality environments, in the suburbs. Smaller households of couples without children, retirees and students remain in the centre. Unlike sprawl in the US, the city centre is not abandoned to low income groups and remains a desirable place to live. However, the process results in families with children being increasingly located in the growing residential suburbs.

In Brussels, although the centre is desirable, the suburbs are seen as vibrant places to live. Typically, according to an official in the Ministry of the Brussels Capital Region, Land use Planning and Housing Administration, with reference to Waterloo Brabant, a wealthy Brussels suburb, *'to live in Waterloo, in a little farm, with a Labrador and a red sport car has been the symbol of success for quite a long time'*. Agriculture has decreased in the area, the land having been transformed into golf courses or into housing developments consisting of 'great villas'. Services are of good quality, for instance, a communal swimming pool, two sport centres and several schools. This success of the suburbs is in part due to the role of Brussels as the centre of the European Union which allows it to attract a very wealthy community.

In terms of the process of sprawl, another common factor mentioned for all case cities is the enabling presence of the transport infrastructure which is seen as encouraging the growth of the city towards the periphery. In Brussels, the development of the circular highway around Brussels between 1967-1999 is seen as a dominant factor. The highway enabled the movement of heavy industry outwards to peripheral cities of 50,000 to 100,000 population. This movement is cited as urban sprawl primarily due to increased commuting from cities such as Aalst and Louvain la Neuve to Brussels. Other peripheral cities such as Leuven and Mechelen are more autonomous from

Brussels. The cities are all distinct physical entities separated by rural areas. These cities to some extent can be seen as part of a polycentric framework at a regional scales, however, there is still a strong functional relationship to Brussels and high levels of commuting characteristic of sprawl.

This is in part due to conflict among the administrators of the three regions. The Brussels Capital region encourages radial movements and commuters to the city; the Flemish region prefers autonomous medium-sized cities, connected to each other by belt (ring) highways around Brussels; and the Walloon region encourages the movement of population from Brussels as it benefits from the population growth. It should be noted that there was a conflict of opinion over the extent of polycentricity in the Flemish region, with some interviewees seeing radial flows to Brussels, characteristic of sprawl as more dominant than 'rocade' flows between the smaller cities, characteristic of a polycentric network.

Administrative competition between the Brussels centre and the outer regions is clear, with the southern Walloon region encouraging growth and migration from Brussels, while at the same time the Flemish region is competing for growth of its peripheral cities. There is little interaction between regions, and Flemish and Walloon regions do not see Brussels as their concern. The main negative effects of sprawl are felt in Brussels, which faces a declining and ageing population, increased commuting and some decrease of commercial activity.

Sprawl in Brussels is a confusing mixture of polycentric cities, suburban fringes and peripheral fringes. The positive impacts associated with the polycentric development pattern are not fully present despite the existence of autonomous cities, as the region still faces high levels of commuting and private car use and retains a strong connection to the Brussels urban centre. It also exhibits some of the spatial patterns of US style sprawl in the movement of population to the suburbs, but has managed to retain a strong centre, in part due to stronger planning measures, but also to its presence in Europe.

In Milan, the pattern of growth is also outward towards urban centres in the periphery.

As with Brussels, the centre remains strong with tertiary, financial and cultural activities increasing. Unlike Brussels where the move out of the city is due to competing attractions between regions and regional planning attempts to bring population back to the urban centre, outward growth in Milan is seen as a result of planning mistakes in the 1953 local development plan which limited the amount of new building in the city boundaries. This resulted in population relocating to surrounding areas. Further mistakes are perceived as policies in the 1970 and 1990s to regenerate surrounding municipalities, and this has created new attraction nodes in the area and resulted in further decentralisation from secondary cities to their peripheries.

In Milan, as in Brussels the movement out of the urban centre is due to high land costs in the city, while the centre remains popular for 'city users' and younger people. People in effect are forced out unwillingly. Unlike Brussels where the poorer neighbourhoods are located in the urban centre, the less wealthy in Milan move to poorer neighbourhoods in the inner ring where commuting costs are cheap. There is also an influx of immigrants from Eastern Europe and North Africa who locate in cheap public housing in the peripheral locations.

Urban sprawl in general is seen as something characteristic of the US, and not applicable to the case of Milan because of its strong history, local identity and quality of life. Sprawl is perceived as a negative spread of development evenly across the land. Under sprawl, the city is composed mostly of suburbs with a beautiful periphery in the 'garden city' model, but while aesthetically beautiful this deprives the city of an identity. Atlanta, Georgia is cited as being a typical example of this type of sprawl. Sprawl is seen as the presence of urban 'anomie' - for example, long distances between places, but in Milan the environment is diverse whether one travels a long way or a short way.

Unlike the typical sprawl in US cities, sprawl in Milan seen as being characterized by a centre which remains strong for tertiary services and higher order urban functions. The Milan centre is unrivalled by the suburbs which lack competing services and character. In the inner ring, the situation is similar to the US with poor quality services and unplanned growth. Meanwhile growth in surrounding cities is characterized by high accessibility, supply of services and high quality of life, which is seen as having a better quality than the North American suburban archetype. This is attributed by an expert at the Polytechnic of Milan, primarily to the strong history in the area, which is seen as a source of pride - *'From Milan to Monza one finds a strong local identity, built from history and rooted in the centuries. Going to the South one finds a similar situation...in the hinterland there is a rich history. The problem lies in the area closer to the city.'* The Milan region is perceived not as having a uniform spread of development, typical of sprawl in North America, but as composed of several urban centres, which although not as rich in character as the urban centre, provide high quality services and urban environment.

The pattern is not as straightforward as the typology of the peripheral fringe suggests, as in Milan the better off move further out to the outer ring where housing and environmental conditions are better. The less desirable areas are thus not beyond the residential suburbs but closer to the centre. Urban sprawl reflects a contradiction of interest – there is a movement away from the centre and its immediate periphery where the environment is less desirable, yet at the same time there is a phenomenon of 'new urbanization': the active population wants to be near the jobs and therefore they try hard to re-enter the city centre.

Sprawl is once again is seen as part of the demand for families for more space and also to the appeal of the 'garden city'. As stated by an expert at the Polytechnic of Milan: *'Sprawl and re-urbanization are legacies of the requirements of families and these are tied to their cycle of life. A family with children who go to school has different requirements from the same family before they have children and after the children are grown. Which of these goes to live in New York'.*

Partly due to the strong historical identity in this area, solutions for urban sprawl aim to reconstruct local identities and urban communities – creating smaller administrative boundaries focused on an historic area is seen as the way to combat sprawl - although cooperation between local authorities is encouraged. There is however little support for cooperation at higher institutional levels. There was little focus on transport policies as it was felt by an official at the Agenzia Mobilita e Ambiente of Milan that *'in the areas* *characterised by highly dispersed settlements and low density the possibility to limit the use of car and to promote public transport remains remote..'*

In Milan there is a similar desire for coordinated regional policies but common agreement among those interviewed that there is a lack of shared vision for the region. Planning is felt to be weak in comparison with private speculators who have more power to shape the urban region. Regeneration policies on brownfield lands is mostly speculative and although the aim is to create mixed functions, the priority is to maximise returns on the land which often results in mainly residential development as this takes the highest market value.

Sprawl in Milan is closest to the idea of sprawl of the peripheral fringe and although the region is not seen as suffering from the archetype of North American sprawl, yet even here many characteristics of scattered suburban sprawl exist in the movement of families to the outer ring. There is also a contradiction in the centre between the strong commercial and retail services juxtaposed with poor immigrant communities. The centre although vibrant faces the problem of declining population and support for low income groups.

In Helsinki, urban sprawl and urban growth are seen as one and the same. Sprawl is felt to be confined to the Helsinki Metropolitan Area (HMA), where the dominance and attraction of Helsinki serves as the focus for growth. Sprawl pulls development which would otherwise be located in the city centre to the rest of the metropolitan area. Sprawl is due mostly to the attraction from rural areas to Helsinki – sprawl is less regional and presents itself at the city level. This is unlike Milan and Brussels which compete with other urban areas for their share of growth.

There was no clear consensus on the pattern of urban sprawl. Some commentators saw the HMA as a multi-centred region with the inner city and regional centres. However, others see it is mainly as scattered development. Interestingly, barriers to growth lie in language barriers between Finnish speaking areas and minority areas, such as at the eastern boundary of Helsinki. The outer area of HMA is the location of lower income groups who moved in from rural areas during the 1960s and 1970s. Real estate here is cheaply constructed and does not attract higher income residents.

A shared factor with the other case cities is the movement of young families out of the centre due to high land rents - families with children have moved from the centre of Helsinki to the outer rings where housing is more affordable. According to an official at the Helsinki Metropolitan Area Council *'A significant factor, particularly in the HMA, is the sense of rootlessness felt by those moving from the country to the city.'*

The main impact of sprawl is the reduction of open space, although much of this is accepted as an inevitable consequence of urban growth. A typical comment, as stated by an official at the Helsinki Metropoltan Area Council was *'the amount of open space in Helsinki Metropolitan area has reduced. The critical question is how much of this change can be considered as a natural part of city growth and how much due to urban sprawl.'*

As with the other case cities, transport networks are seen as the main enabling factor. Helsinki is seen as having a fragmented urban character with growth dispersing outward. The area remains an attraction for commuters with the commuting zone increasing between 1980-1999 and traffic congestion along with loss of rural land is seen as the major problem of urban sprawl. However, although this is not as bad as in other countries, it is higher than in the rest of Finland. Public transport is not seen as a feasible solution as employment is located in specialized clusters making use of public transport difficult. Fragmentation of governance at a municipal level is not seen as contributing to sprawl – the separation of planning and transport policies at the local level is seen as more important.

Sprawl in Helsinki is perceived as a local problem – despite the impetus for growth due to migration to Helsinki at a national level and the spread of development over the Helsinki Metropolitan Area. On the whole, sprawl is not seen as a major problem, and any negative effects are accepted as a necessary part of the economic growth of Helsinki and the Helsinki Metropolitan Area. A factor in common with Brussels and Milan is the movement of families with children to the suburbs, and the location of immigrants in a deprived area of the periphery.

In Rennes, sprawl is seen as the growth of small towns and villages in the surrounding area which has occurred in the short period from 1970-1990. Growth in Rennes has traditionally been focused on the city centre due to renewal projects aimed at improving social housing and industrial areas. This has resulted in development which is highly self-contained with little or no suburbanization or strip development, but from the 1980's development has spread to towns around Rennes. The presence of a green belt (ceinture verte) around Rennes has helped avoid the growth of suburbs. Development is focused on these surrounding towns and villages, rather than on Rennes itself, in what appears to be a polycentric pattern. Most of this growth is due to migration of people from other parts of France to Rennes.

Most new building and employment is evenly spread between Rennes and surrounding municipalities. This is a result of the agricultural nature of the surrounding area, with Rennes as the dominant attraction in the region, and also due to the strong level of planning control by the municipality. The 'land allocation plan' is legally binding and Rennes Metropole holds publicly owned land. Developers must therefore bargain with the municipalities for development rights. This high level of control over development results in what is seen as a balanced level of growth in Rennes.

Urban sprawl is not seen as a problem in Rennes – sprawl is defined by experts in Rennes as the contiguous expansion of the centre into the suburbs, which does not exist in Rennes due to its green belt. Rennes and surrounding municipalities welcome growth and the main problem is seen as the provision of housing for new workers or keeping pace with growth. Sprawl is primarily a concern of the rural authorities who are trying to prevent growth in their towns rather than the urban authorities. The burden is high on these authorities who are under pressure to provide a high level of service comparable to that in the central area. As in other case cities, the centre of Rennes has a concentration of students and older people. It is also a prime location and offers a strong quality of life (public spaces, architecture, services). In Rennes, young families and children leaving home are not able to afford rents in the centre so have to move further out.

Despite the concentrated growth and control over development, Rennes faces many costs associated with sprawl, namely increased commuting to Rennes and lack of public transport. Although growth is concentrated in a few nodes, public transport is not seen as feasible due to the distant nature of the municipalities and the transport lines crossing areas of very low density. A problem of sprawl common at the early stages of the process is the transformation of rural land to housing. In Rennes farmers prefer to sell their land to new residents for housing, while those who prefer to remain in agriculture become rural zones surrounded by residential development, which makes it difficult to continue farming. There is no coordination between municipalities in Rennes and loss of control is strongly opposed by mayors in smaller municipalities whose main aim is to keep growth out. High density in the smaller municipalities is associated with social housing and unaesthetic development.

Stuttgart on the whole faces a problem of uncoordinated, unplanned growth. Sprawl tends to be contiguous with land developing between transport axes. Although growth is accommodated on green field land, there is some planning control with development directed to former military bases. Sprawl is also ironically seen as a result of problems of urban planning, as was the case in Milan, as the reform of municipality boundaries in 1974 did not allocate new land to Stuttgart. As a result the pressures for growth could not be accommodated within the present land area and as such growth has to occur across the boundaries of Stuttgart. Sprawl is therefore an almost inevitable part of urban growth.

The characteristics of sprawl are similar to the other case cities. There is a movement of families with young children out of the city centre due to high land prices. Despite an overall loss of population from Stuttgart, demand for housing in the centre is high with many young families moving out because they are unable to find an apartment in the city. Stuttgart is seen as the location of choice, as stated by an expert in sprawl from the Stuttgart region, *'Stuttgart always has its flair. The population of the city like to live – after different questioning – in Stuttgart'*. Unlike sprawl in the US, there is no fear of high density living, according to an expert from the Stuttgart region *'the residential density has, after questioning of the population to the reasons for location choice played a rather low* *role, compared with the local environment.'*

Stuttgart also faces consequences of sprawl due to the migration of Eastern Europeans, particularly Bosnians who had previously located in the city centre and have recently emigrated. There has also been the movement of the service industry to the outer regions of Vaihingen, Moehringen, and Feuerbach. Particular mention is made of the musical hall 'Stella' - which is a cluster of leisure industries which has drawn many service sector industries out towards the periphery. Despite this movement of population and services out of the city centre, a large proportion of commuting is focused on Stuttgart. Recently there has been some reoccupation of the city centre due to falling rents, and the re-immigration of Bosnians.

Sprawl is seen as a threat to Stuttgart, drawing income away from the city to surrounding municipalities, unlike Rennes where sprawl brings lower income and higher density to small towns. The main problem is congestion with commuting between Stuttgart and surrounding municipalities. However, some of the increase in commuting is not perceived to be related to land use patterns, but due to increased availability of the private car due to rising incomes This has resulted in an increase in traffic without observation of urban sprawl. The second main cost is the loss of agricultural land which has been converted to industry. Agricultural areas which remain are becoming too small to be profitable.

Sprawl clearly has impacts outside the boundary of Stuttgart – the city of Filderstadt mirrors events in Stuttgart – for example, high land and house prices in Stuttgart are a reason for the movement of population to Filder (and after a time lag, prices also increase in Filder) which is a popular area due to its good accessibility and landscape. It is a dormitory community with higher levels of out commuting, with people working in Stuttgart or in the Leinfelden-Echterdingen (the airport) area. Services are seen as very good in Filder although people remain orientated to Stuttgart.

There is no regional policy to tackle sprawl, although there is a regional municipality called the Verband Region Stuttgart, founded in 1994, which gives the region political representation. Although one solution to sprawl is seen as limiting the growth in the outlying municipality of Filderstadt, no coordinated policies were discussed. The main policy has been to increase public transport and to cope with increased traffic by an eastern by-pass of the centre. City level policies focus on bringing business back to the centre by making parking lots free in the centre of outlying municipalities, which lost business to the department stores in 'the green meadow' or green field areas. There seems to be a conflict in desire to increase modal share to non-motorized transport and public transport, and the acceptance of the dominance of private car use. There is hope pinned on Stuttgart 21 – a planning area for the Stuttgart Trade Fair and the plans for Olympia 21 as a force of attraction to Stuttgart.

4.5 Perceptions of Sprawl in Bristol

The case city of Bristol is given special attention in this discussion as it has been seen as the most extreme example of sprawl among the case cities, and the closest to the US pattern of edge city development, according to an official from the Joint Strategic Planning and Transportation Unit *'there is also some evidence that US models of suburban development were influential in shaping attitudes to the form and design of key developments.'*

The spatial structure of British cities is one of a highly polycentric pattern of settlement structure, dominated by areas of high urban densities, where many large cities dominate a series of medium and small towns in densely populated rural areas. This contrasts with the other territorial typologies identified in the rest of Europe, namely regions dominated by a large metropolis in a densely populated rural area; polycentric regions with high urban densities in less dense rural areas; networks of small and medium sized towns in medium density rural areas; and remote rural areas (ESPRIN UK, 2000) .

The Bristol region is described as polycentric in form (Coombes and Wymer, 2001; ESPRIN UK, 2000), extending east to merge with the polycentric development of the London-Bristol western corridor at an intra urban scale. Interestingly the patterns of local linkages identified Bristol, Weston-super-Mare and Bath as separate entities, with interconnections identified from a combination of spatial relationships including historical association, recent migration linkages, and commuting patterns. The approach assesses the linkages between building block areas, and then connects these to form clusters of highly interactive areas. Figure 4.5 shows connecting pairs of wards with the highest interaction scores (Coombes and Wymer, 2001).

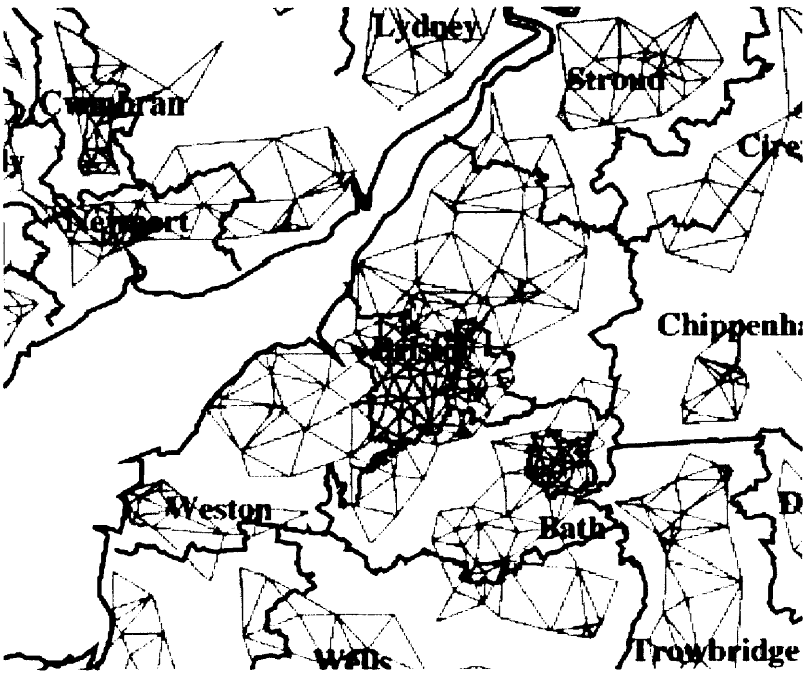

Figure 4.5: Structure of the Bristol Region (ESPRIN UK, 2000)

Despite this assessment of polycentricity at the regional scale, the focus of the interviewees was on sprawl between Bristol and the North Fringe (located north of Bristol between the M5 and M4, in the outer urban ring, see Figure 4.6 andFigure 4.7). The area is contiguous to the Bristol urban area, a pattern of development not usually defined as urban sprawl, yet according to experts interviewed displays signs of classic urban sprawl and 'edge city' development. This contiguity is seen as one of the main reasons for the negative impacts of the sprawl of the North Fringe on Bristol, according to an official from the City of Bristol *'The city has got to try to redevelop outside its boundaries. And that brings it into conflict with its neighbouring councils because the administrative boundary of Bristol is very tight and runs through the urban area rather than around it.'* The consequences of sprawl are present in pressures upon the Bristol City Centre, yet this results not from the scattered urban form or unplanned development described in the literature but from the conflicting aims of local authorities in the region. For example, despite the presence of low density development in the area of urban sprawl, problems of transportation and service provision are linked less to density than to conflict and disagreement among authorities.

The North Fringe has remained clearly outside the control of Bristol City Council, with development influenced by the growth strategy not only of the (former) Northavon Council but also by national influences towards laissez faire planning. The pro-development Northavon council seized its chance to attract development particularly in light of loosening planning controls nationally. This is set out in the Avon County Structure Plan of 1980 which favoured the North Fringe as an area of limited development, setting targets of 0.8 km^2 of warehouse development, 0.5 km^2 for industry and 50,000 m^2 for office space. Pressure for large scale retailing increased in the mid 1980's with these development applications supported by the Northavon District Council. Despite initial refusals for a regional shopping centre by the Secretary of State, the applicants and Northavon District Council, continued to press for development, eventually winning their appeal in 1991.

The North Fringe can be interpreted not as unplanned growth, as although this is private sector led development, it is also 'sprawl' planned for, created by and endorsed by the local authority itself. It is the administrative conflict and lack of regional level coordination which has lead to the characteristics of urban sprawl, with the primary opponents tellingly being Bristol Council, which bears the main brunt of the effects and the Joint Strategic Planning and Transportation Unit (JSPTU), the body responsible for regional planning.

In fact, the JSPTU rather more than the individual local authorities sees the area as a polycentric network, and views the vision for its development as a network between Bristol, Bath and Weston-super-Mare with Bristol as the primary centre. The local authorities at Bath in particular and to some extent Weston-super-Mare see their development as a separate issue from the development tensions in the urban centre at Bristol. For instance, planners interviewed at Bath were hostile to growth and emphasized their status as a world heritage site as a limiting factor. The problems of Bristol and the North Fringe were not a concern, with the main emphasis to preserve the green belt around the city of Bath, despite the ties to Bristol for housing and commuting to schools in Bath by those in Bristol.

Figure 4.6: The Bristol study area at 1: 250,000 scale.
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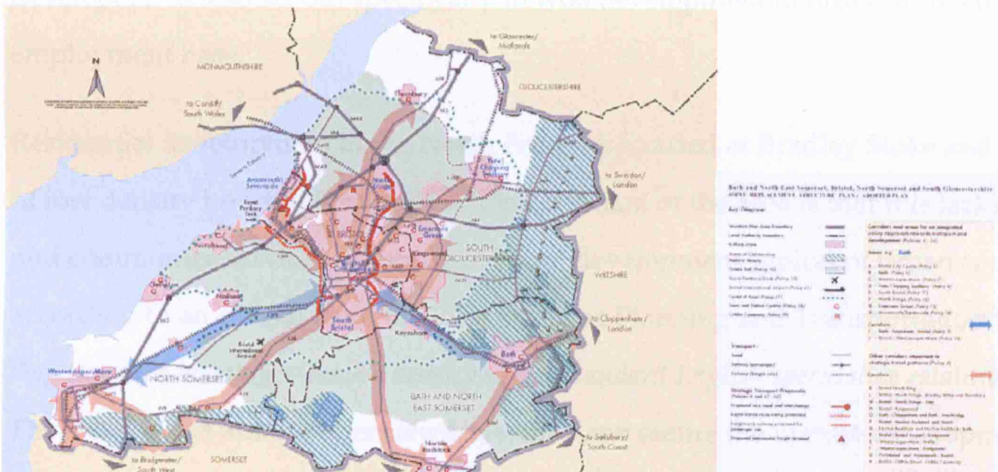


Figure 4.7: Regional structure plan former county of Avon (JSPTU, 2002)

4.6 Characteristics of Sprawl in the Bristol Case City

The major characteristic of sprawl in Bristol has been the development of the North Fringe primarily in the 1980s. This consists of the regional shopping centre at Cribbs Causeway, new areas of low density housing development in Bradley Stoke (see Figures 4.7 and 4.8) and the attraction of new economic development to the Aztec West Business Park consisting both of relocation of industries from Bristol City Centre (Axa Sun Life Insurance and Royal Mail) and the attraction of new industry such as Orange Telecommunications, Hewlett Packard and the Ministry of Defence against national competition.

The North Fringe is attractive due to its ability to offer a US style office park environment with large sites, a variety of property types and sizes, a variety of real estate arrangements and ample parking. The second attraction is the good transport links to London and the south east, attributes not offered in the centre city of Bristol. While good transport links created an attraction for the region in general, the North Fringe offered a pro-development / pro-growth environment which was attractive to developers. It also set out specifically to woo development in order to sustain the local employment base.

Residential development in the North Fringe is focused at Bradley Stoke and consists of low density housing for families. One criticism of the area is that it is lacking social and community services, resulting in bland development typical of urban sprawl, according to an official from the Joint Strategic Planning and Transportation Unit, of *'bog standard housing ...lowish density sort of standard English speculative estate housing'.* There is conflict among interviewees, with some seeing the mature development as a success story which is much in demand by young owner occupiers, while others see the attempt to attract local services as a failure. These commentators cite out-of-centre retail and large food stores within a five to ten minute drive as the main reason for failure. The few local services on offer were poorly planned and oriented to car users, according to an official from the Joint Strategic Planning and Transportation Unit , *'I'll tell you how local shops and pubs and fast food restaurants spread on four sides of the roundabout with no segregated crossing....which is very badly done'.*

This is typical of the strip development of US style sprawl. However, the growth of out-of-centre retail and housing has not led to the decline of the Bristol City Centre. The desirability of the city centre is less so than in the other European case studies, and the centre less robust to peripheral residential development but it has remained viable. Additionally, there have been recent attempts to strengthen the small retail development at Bradley Stoke, placing its early development as one stage in the process of growth, with its more mature form as a more sustainable neighbourhood.

The two fold competition between Bristol and Northavon and lack of control over the development aspirations of Northavon are mentioned as a major factor in the development of urban sprawl. The attraction of new industry such as Hewlett Packard and Orange Telecommunications is seen by the economic experts interviewed as a bonus for the area as a whole, with the North Fringe attracting new industry which would not otherwise have located in the city centre. This view is not shared by all interviewees with the regional planning body interpreting this job growth as mostly displacement from the Bristol city centre. The benefits of this growth have not been shared by all parts of Bristol – particularly South Bristol which lost employment due to the decline of traditional industries of tobacco and packaging. It seems undoubted that the North Fringe has provided real job growth, and to some extent the different interpretation of its impacts stem from different ideological approaches to development and planning.

Despite the conflicting opinions, the development of this type of 'sprawl' has not created the 'doughnut' effect typical of sprawl in the US There is a wide-spread view that the North Fringe initially pulled investment out of the city centre, resulting in the abandonment of regeneration schemes in the 1980's. This negative trend is believed to have turned and feeling for the strength of the city centre is generally positive. Although it has been acknowledged that retail development in particular has been hurt by out-of-town developments, the centre is seen as making a comeback with several opportunities. For example, recent reversals are cited as the Bristol Harbourside residential and leisure complex, and Temple Quay office development. According to an official from the City of Bristol, *'Sooner or later there will be a battle between the centre and the outer fringe...It's a battle that probably the city centre is winning at the moment.'*

This is partly due to congestion and over development in the North Fringe reducing the attractiveness of the area.

Recent years have seen a cooling of growth in the former Northavon council (now South Gloucestershire); however coordination between local authorities is still limited to the interests of the JSPTU. The expressions of interest for cooperation, according to an official from the Joint Strategic Planning and Transportation Unit, *'there have been other councils in the area who have other aspirations, which are kind of complementary...so they do have some aims in common on the face of it'* is not a major objective of the local councils. The council calling most for restraint is Bristol as it has declining industries in South Bristol and would like to capture some of the growth in the North Fringe. This claim is also made for North Somerset which includes Weston- super-Mare, although there is a less immediate interest in this council. The new council of South Gloucestershire has recently attempted to restructure development, primarily due to loss of investment stemming from the externalities of sprawl. According to an official from South Gloucestershire Council, *'They were worried about the pace and whether it had spread to some of the villages and towns of South Gloucestershire and turn it into a continuous urban area that would ultimately become part of Bristol.'*

The main problems of sprawl are the lack of services detailed above, and the level of congestion on roads to the North Fringe, particularly at peak hours, related to the high levels of car use. Commuting to the North Fringe is seen as inevitable given its location on the motorway and adjacency to a major city. Areas of heavy congestion, poor environmental conditions and recurrent traffic problems are primarily to the north of Bristol along the A38, A4018, but also on routes entering the urban centre from the east along the A420 and A431, and to the south along the A37. Problems affect not only Bristol, but also areas in the hinterland from Bath along the A4 towards Bristol and from Weston-super-Mare along the M5. This is one reason for the movement back to the city centre from the North Fringe. According to an official from the Bristol City Council, *'the quality of development is better within the city centre. The accessibility is better and the public transport is better.'*

Accessibility in the area is primarily through the private car and in the past the focus was on improvements to the local road system. The regional structure plan pushes for provision of infrastructure for public transport through light rail transport (LRT) which would link the North Fringe to the city centre. This was stalled until recently due to disagreement between Bristol and South Gloucestershire local authorities over the proposed route and location of stations. Whether this goes through or not interviewees expressed concern that the orientation of the North Fringe to the private car and the low employment density would be a barrier to any such modal shift.

Other areas of potential growth outside of Bristol City are Weston-super-Mare and Yate /Chipping Sodbury in South Gloucestershire, see Figures 4.7 and 4.8. Weston-super-Mare has seen a growth in residential expansion, although this has not kept pace with job growth, resulting in increased commuting to jobs elsewhere, particularly in road travel to Bristol and the North Fringe. The area also faces competition from regional shopping centres at Cribbs Causeway which is threatening town centre shopping and retail facilities. Although Weston-super-Mare would benefit from restrained growth in the North Fringe, there is less focus on the impacts of this area on Weston- super-Mare, and the area is starting to see some commercial enquiries from spillover in the North Fringe.

Bath is the second major town in the region. However due to its status as a world heritage site, it is not a major contributor to growth. The city is however facing large development pressures arising out of small office based businesses and the retail, tourist and leisure sectors, and through rising commuters from the sub region.

This pro-growth / anti-growth stance is a major divider among commentators on sprawl in the region. The JSPTU and Bristol Council for example, take an anti-growth stance, with the growth of the North Fringe as detrimental to Bristol drawing jobs out of the centre with little new job growth. Other experts prefer a pro-growth stance, with this market led development seen as good for the region and a developer of new economic growth. This comes through in the planning policies of the region, which also reveal the competition for growth among local authorities.

4.6.1 *Regional Policies for Coordinated Growth*

Policies in place to minimize sprawl can be seen in the Joint Replacement Structure Plan (JSPTU, 2002). The JSPTU stresses the importance of integration between land use and transport, and reduction of the average length and number of motorised journeys, particularly in travelling to work. As such it promotes the placement of jobs and homes in close proximity, or with effective linkage by public transport. The aim is to concentrate housing and economic development adjacent to Bath, Bristol and Weston-super-Mare in accordance with current green belt policy. The green belt is retained, although boundaries at Keynsham (in the outer urban ring between Bristol and Bath) could be altered to develop housing requirements, employment and social infrastructure.

New housing is to be placed within urban areas, or immediately adjoining as urban extensions. However development out of step with employment is discouraged as this leads to increase in car borne commuting. New development which is out-of-town is to be focused around areas with better public transport access, mainly on the strategic public transport network linking Bristol, Bath, Weston-super-Mare and Yate / Chipping Sodbury, and at other settlements which offer the ability to provide public transport to the main centres. Improvements to public transport are encouraged, to provide housing near to major retail, leisure, commercial, health and education services particularly in Bristol, the North Fringe and Bath. Villages and smaller towns covered by green belt policies are considered unsuitable for development, and will only be considered if adequate public transport can be guaranteed.

Bristol is the focus for employment growth, with the potential jobs to be located within or immediately adjacent to the Bristol conurbation, with a main aim being the regeneration of the Bristol City Centre, and secondary to that a better jobs housing balance in South Bristol and Weston-super-Mare. Other areas earmarked for future economic development are Avonmouth/Severnside and Royal Portbury in south Bristol, and Emersons Green in South Gloucestershire. However despite the physical proximity of employment and services, development of this area is dependent on improvements to transport infrastructure. In particular, the plan seeks to restrain the development of employment in the North Fringe of Bristol, by diversifying existing employment commitments particularly for housing, and prioritising job creation elsewhere.

Bristol, Bath and Weston-super-Mare are the main focus for major retail development, with enhancement of local shopping facilities. New retail is proposed in Bristol City Centre, Emersons Green and Bradley Stoke in South Gloucestershire, along with Bath and Weston-super-Mare. The aim is to strengthen these centres for comparison shopping and to prevent expansion of out-of-town shopping, regional shopping centre development and other major outlets.

Policies to improve congestion focus on increasing the accessibility from Kingswood to the North Fringe, promoting rail service from Bath and improving congestion on the approach to Bristol city centre and the north fringe. Planned improvements to public transport include the Bristol – North Fringe Light Rapid Transit which would distribute trips to destinations in North and Central Bristol; and transit providing both radial movements from the Bristol Centre and Orbital Movements between the main centres in the region. Bristol City Council and South Gloucestershire Council are working on an LRT north of Bristol City Centre to Parkway and from the City Centre to the Cribbs Causeway line. These policies detail the implementation of the compact city focusing employment and services around existing centres, restricting the growth of out-of-town shopping centres, and limiting residential development to infill within existing centres. The main focus of the JSPTU is to pull development back towards Bristol.

4.7 Policies for Development in the Local Authorities of the Bristol Case City

4.7.1 Bristol City

Bristol City sees itself as the centre of development in the region (Bristol City Council, 1997), but recognizes the role of the regional centres to its prosperity, with the city as the core of a sub region composed of the city centre, as well as Avonmouth, South Bristol and South Gloucestershire as areas for economic investment. The priority for Bristol City is employment generation to offset loses in defence employment, and manufacturing sectors. In terms of employment generation, mixed use development within the city centre is encouraged; however sites outside the city centre are also earmarked for new office development. Industrial and commercial regeneration are focused at the city centre, Avonmouth and South Bristol. This is in line with the vision of the JSPTU which sees the focus of economic investment at Avonmouth / Severnside, Royal Portbury Docks and to a lesser extent Emersons Green.

Housing demand has increased due to trends in smaller households and in migration to the area. Strong employment growth of the Bristol area during the 1970's and 1980's has attracted population to the surrounding areas, such as the North Fringe, and at the same time population growth within Bristol has spilled over into locations on the fringe. It is felt that Bristol city cannot accommodate these numbers within the city boundary, and that movement to new housing outside the city such as at Bradley Stoke is acceptable.

In terms of retail development, Bristol City views the retail development at Cribbs Causeway, and the adjoining areas of Stoke Gifford, Filton and Oldland as major competitors with city centre shopping areas such as Broadmead, which is also promoted as a regional centre. Out-of-centre shopping is supported only if there is no opportunity to provide modern facilities within or adjoining existing centres, and if an out-of-centre scheme does not cause demonstrable harm to the vitality of existing centres.

4.7.2 South Gloucestershire

The South Gloucestershire local plan (South Gloucestershire Council, 2002) seeks to consolidate the growth which has already been achieved over the last thirty years. The area still sees itself as a focus for growth, for example, Emersons Green to the east of the Avon ring road is earmarked for new development, due to lack of capacity for infilling in existing centres. Additionally, although preservation of the green belt is supported, limited infilling in existing green belt settlements is encouraged at centres adjoining Bristol and the North Fringe.

There is greater recognition of the impact of Cribbs Causeway in particular on local centres. This is primarily due to the impact on centres within South Gloucestershire, such as at Emersons Green and Bradley Stoke, rather than the City of Bristol. In particular, there is a recognition of the contribution to traffic congestion and lack of physical and social infrastructure. There is stress on improving the transportation infrastructure to the Mall and Cribbs Causeway through the proposed LRT with development in the North Fringe.

4.7.3 *City of Bath*

Bath Local Plan (Bath City Council, 1997) is seen as an important centre for employment for Bristol, North and West Wiltshire, and Northavon. The city is a world heritage site which precludes major development or redevelopment, particularly of housing, due to the form and character of the city. The county council has restricted the allocation of residential development in the city in order to safeguard its unique character, and development beyond infilling is not permitted. The City's housing needs are unlikely to be met by existing or planned development, and while population is stable at 80,000, changes in the household age structure are likely to increase the demand for housing. Pressures for growth are thus pushed outward to South Gloucestershire and the City of Bristol.

4.7.4 *North Somerset*

North Somerset (North Somerset Council, 2000) is a fast growing area with an 8.4 percent increase in population since 1991, with development centred around Weston-super-Mare, Nailsea and Clevedon. Weston-super-Mare is largely reliant on Bristol for employment, and lack of infrastructure has lead to an increase in commuting problems. The area is seeking to develop its manufacturing base, at Portishead and Yatton Cleverham located in the hinterland between south Bristol and Weston-super-Mare, as a way to reduce dependency on areas outside of North Somerset for employment. This places North Somerset in opposition to the regional development plan, which aims to focus manufacturing growth at Avonmouth/Severnside within Bristol City . The area is also seeking to strengthen its retail position in the face of competition from Cribbs Causeway by developing existing town centres at Weston-super-Mare, and other smaller foci in North Somerset such as the Clevedon Triangle, Nailsea, and Portishead.

4.8 Summary

Sprawl in Bristol reflects a confusing mix of polycentric development, scattered suburban and strip malls, and business centres. It cannot be pigeonholed into either of these typologies and shows a series of both positive and negative feedbacks to the city centre and the region. The negative impacts relate not so much to the low density of development or to the physical form but to the spread of development across administrative boundaries. It shares similarities with the other case cities in that the suburban residential development is the location of choice for young families, and in the relative strength of the city centre. The centres of Bath and Weston-super-Mare have not been influential as poles of growth partly due to specific local restrictions.

The North Fringe is contiguous to Bristol City Centre and the negative impacts of sprawl such as drawing commercial and retail development away from the centre are due less to the urban form and more to the division of the urban area by administrative boundaries. Bristol itself, as expressed in its local plan recognizes that the full scale of residential and commercial development could not be accommodated in the centre. This 'sprawl' can be interpreted as an inevitable part of the booming economic growth in the region. It is also unlike expressions of sprawl in the literature in that although consisting of private sector development, this was planned for and supported by Northavon. The major impact is on commuting and congestion with lack of public transport related to administrative conflict.

Despite the surface appearance of exemplifying the type of sprawl described in the literature, the nature of sprawl in Bristol is influenced by a strong planning tradition, evidenced by the change in strategy of the new council of South Gloucestershire to reign in growth, the potential viability of public transport through the LRT and the continued strength of the city centre despite competing attractions.

The case cities present certain commonalities in the movement of young families to the suburbs, the presence of areas inhabited by recent immigrants and the sustainability of the city centres. There is also a common problem of traffic congestion which occurs even in well contained cities such as Rennes with concentrated growth poles and strong planning control. In addition, the development of urban sprawl is related to the inability of the city centre to contain increasing growth and development within existing boundaries. With the case of high land rents in the city, it is in some sense even initiated by processes in the centre.

In the case of Milan, Stuttgart and Bristol, sprawl can be tied to specific planning policies rather than to unplanned growth. Uncoordinated growth – with the different agendas of neighbouring local authorities contributing to the impacts of sprawl - is a repeated occurrence. In this sense sprawl is part of urban growth and its impacts are tied to broader societal changes, unrelated to urban form, such as increased car use. The definition of urban sprawl as derived from the various interviews cannot be tied to any particular typology but they exhibit common features across a variety of urban forms. Chapter five discusses the results obtained from measures of sprawl and looks at the patterns and results of sprawl emerging from a more structured, quantitative interpretation.

Chapter 5

Statistical and Policy Analysis of Sprawl in the Case Cities

5.1 Introduction

This chapter discusses the statistical analysis of sprawl used in the SCATTER project. It complements the qualitative interpretation of sprawl obtained through the expert interviews by using quantitative measures which compare the nature of sprawl across the case cities and provide some clarity to the interpretations made by the local authorities. Sprawl is a complex phenomenon. Quantifying its pattern of growth allows for a clear conceptualization of the problem and allows for the assessment of sprawl as a process through exploration of the dynamics of urban growth over time. This chapter examines the identification of sprawl using quantitative measures, looking particularly at the ability to identify sprawl at the scale and density of development in European cities. The view of sprawl revealed by the quantitative measures is contrasted with that obtained from the qualitative interviews of the SCATTER project.

5.1.1 Measures of Sprawl

The measures of sprawl were based on population and employment data focusing on the change over time. Three measures were used: the temporal mean growth rate, a measure of concentration termed the H-measure, and local spatial autocorrelation statistics. The measures were applied to obtain a picture of sprawl for populations, workplaces, and employees. This assessment of sprawl is based on the use of density and spatial extent as an indicator of urban growth, rather than relating to more direct land use measures.

The statistical analysis is based on zonal time series data over five time periods. The time series covers a period of at least ten years in order to examine the process of urban sprawl. Five time steps were not possible in all cases at the level of detail required. The data sources used for the statistical analysis were based on population and employment data and are described in Table 5.1. The data were collected for each case city over a time span ranging from 10 to 50 years due to differences in data availability for the case cities. The local zones described in Table 5.2 differ in size and are defined by the population count rather than a standard area. The Brussels commune encompasses approximately 20,000 people, the Helsinki postal zone covers approximately 1,000 people, the Rennes commune covers approximately 2,000 to 3,000 people, the Stuttgart commune covers approximately 10,000 to 15,000 persons, the Milan commune covers approximately 20,000 persons and the Bristol ward covers approximately 5,000 persons. Particularly in the case of Helsinki the local zones differ widely in geographical size due to the rural nature of the zones in the hinterland.

The difference in size of the local zones for the case cities results from the differences in population size of the case cities. However, apart from the Local Moran's I, the measures used are based on the zones defined for the SCATTER project (urban centre, outer urban ring and hinterland), therefore the difference in scale of the local zones does not affect the comparability of results.

Table 5.1: Sources of data used for the measures: population and employment

Local definitions and elements: Population			
City	*Definition*	*Source*	*Years of the data*
Bristol	100% census count	UK Census	1971, 1981, 1991
Brussels	Total population by commune	INS, census and demographic statistics	1981, 1987, 1991, 1997, 2000 and 2001
Helsinki	Resident population	Population Register Centre, Statistics Finland	1990, 1994, 1996, 1999
Milan	Resident population	Census and Registry data	1971, 1976, 1981, 1986, 1991, 1996, 2001
Rennes	Population without double account (for example, student are only taken into account at one place)	INSEE, census	1962, 1968, 1975, 1982, 1990 and 1999
Stuttgart	Registered population on its first habitation (normally the place where the people live when they are working)	STALA Baden-Württemberg	1976, 1980, 1884, 1888, 1990 - 2000

Table 5.1 (continued)

Local definitions and elements: Employment			
City	*Definition*	*Source*	*Years of the data*
Bristol	100% census count. employees by place of residence	UK Census	1971, 1981, 1991
Brussels	Total jobs per commune (counted at work place) – excluding self-employees, and people working in the EU institutions Jobs directly induced by the population: include detail trade and services to persons (jobs are counted at the work place)	ONSS (National Social Security Office)	1984, 1987, 1991, 1993, 1996 and 1999
Helsinki	Employed persons registered at the place of work.	Statistics Finland	1990, 1994, 1997, 1999
Milan	Employed persons registered at the place of work: it includes all private and public jobs except 1996 data (only private sectors but agriculture).	Census	1961, 1971, 1981, 1991, 1996, 2001
Rennes	Number of jobs: it includes all private (work for its personal account also) and public jobs	INSEE, census	1982, 1990 and 1999
Stuttgart	Employees liable on social insurance and registered at the workplace	STALA Baden-Württemberg	1976, 1980, 1884, 1888, 1992, 1996, 1997, 1998, 1999

Table 5.2: Sources of data used for the measures: area and distance

Local definitions and elements: total area			
City	*Definition*	*Source*	*Years of the data*
Bristol	Area for each ward is given as an attribute of the digital boundary file	UKBorders digital boundary file for County of Avon by ward	1981
Brussels	Area by commune	INS	1991
Helsinki	Area of each postal zone calculated from the digital coordinate data	Genimap Oy, digital data	2000
Milan	Area by municipality	Census	1991
Rennes	Area of each "commune" of the urban area	INSEE	1999
Stuttgart	Area by commune	STALA Baden-Württemberg	2000

Table 5.2 (continued)

Local definitions and elements: distance between each zone			
City	*Definition*	*Source*	*Years of the data*
Bristol	Matrix indicates distances between centres of wards. Derived using ArcView 3.3 scripts Real Centroid Generator by O. de la Pommeraye and Distance Matrix by Hannah Maoh. Available http://arcscripts.esri.com/	UK Borders digital boundary file for county of Avon by ward	1981
Brussels	Distance as the crow flies between the centres of communes.	Centres of communes from the integrated land-use/transport model (gravity centres with regard to population and economic activities)	1991
Helsinki	The shortest distance between centre coordinates of each postal zone (MAPINFO, centre of gravity method)	Genimap Oy, digital data	2000
Milan	A matrix indicates the distances between barycentres of the municipalities.	Calculation from GIS data	1991
Rennes	A matrix indicates distances between centres of commune	IGN-MAPINFO	1994
Stuttgart	A matrix indicates distances between centres of commune	MAPINFO (Map base: Verband Region Stuttgart)	2000

The measures of sprawl discussed in this chapter form the second stage of the SCATTER project and identify and quantify the effects of urban sprawl using statistical methods. The statistical analysis provided a comparative assessment of the extent of urban sprawl in the six case cities prior to the quantitative evaluation of policies tackling sprawl used in the land use transport model analysis.

5.1.2 *Temporal Mean Growth Rate*

The temporal mean growth rate is derived from the average annual growth rate and the mean deviation of the zonal growth rate, to show the change in the outer urban ring and hinterland over time, compared to the urban centre. It provides some indication of the pace of growth of the cities, an important precursor to sprawl, with faster growing areas more likely to undergo urban sprawl. It can be expressed as the average annual growth rate of the study area where:

$$X^{\alpha}(t+\tau') = X^{\alpha}(t)\exp[\sum_{\tau=0}^{\tau+1}\lambda(t+\tau)\Delta t_{t+\tau}$$

where $X^{\alpha}(t)$ represents the total volume of the variable X at time t, for the whole study area, $\lambda(t+\tau)$ is the growth rate from time t to t+ τ where $\Delta t_{t+\tau}$ is the time difference

5.1.3 *H Measure of Concentration and H^{rel}*

The H measure of concentration describes the level of concentration of the variable where the density of the variable at a particular distance from the city centre is weighted by the squared distance from the city centre, and integrated over the whole case study area. A decrease in the H measure of concentration indicates lower levels of concentration in the region, which coupled with lower densities indicates higher levels of urban sprawl. H^{rel} measures the concentration of development in the outer urban ring and the hinterland combined, relative to the urban centre. If H^{rel} is constant over time this implies that the level of concentration is similar between all zones, although the level of concentration may be changing over time as indicated by the H measure. Higher levels of concentration in the centre have a lower H^{rel}, while greater concentration in the outer urban ring and hinterland results in a higher H^{rel}.

This is expressed as

$$H^{rel} = \int \rho(r) r^2 \, dA(r)$$

where $\rho(r)$ is the density at distance r, r^2 is the distance squared and $dA(r)$ is the integration over the case study area.

5.1.4 *Global and Local Moran's I*

Local and Global Moran's I (Cliff and Ord, 1973; Getis, 1964; Getis and Ord, 1992; Griffith, 1987; Haag, 2002) are used to test for sprawl as spatial autocorrelation occurs where high values are located near to other high values, and low values near to other low values. When high and low values are located near to each other, negative spatial autocorrelation is exhibited. A high value of spatial autocorrelation, greater than 1, indicates a fairly homogeneous neighbourhood, and negative values (less than -0.2) indicate a heterogenous neighbourhood. The measure assumes that a homogeneous neighbourhood is more indicative of urban sprawl, while a heterogeneous neighbourhood is less indicative of sprawl, indicating clusters or poles of growth.

Global Moran's I measures whether high values are located near to each other and low values near to each other. Values near -1 show a strong negative spatial autocorrelation and values near +1 a strong positive spatial auto correlation. It is defined for any variable x_i :

$$I_0(d) = \frac{1}{L}\sum_{i}^{L} I_i(d) = \frac{1}{L}\sum_{i}^{L} z_i \sum_{j,j\neq i}^{L} w_{ij}\, z_j$$
$$= \frac{\sum_{i}^{L}\sum_{j,j\neq i}^{L} w_{ij}\,(x_i - <x>)(x_j - <x>)}{\sigma^2(x)\sum_{i}^{L}\sum_{j,j\neq i}^{L} w_{ij}}$$

where $<x>$ is the mean, and the weights (w) area matrix of binary connectivity between areas, L is the total number of observations for variable x_i and $\sigma^2(x)$ is the variable of (x_i) . If regions *i* and *j* are contiguous *w* =1 otherwise *w*=0. Pairs of regions where one region is above average and the other is below average will contribute a negative to the numerator, hence to negative spatial autocorrelation. Where both regions are above average or below average, this contributes a positive score to the numerator and hence to positive spatial autocorrelation.

Local Moran's I measures the degree of spatial autocorrelation around a specific point and is expressed as:

$$I_i(d) = z_i \sum_{j,j\neq i}^{L} \tilde{w}_{ij}\, z_j$$

where the weights are defined as

$$\tilde{w}_{ij} = w_{ij} \Big/ \sum_{j,j\neq i}^{L} w_{ij}$$

5.2 Densities of the Case Cities

The densities for the case cities provide an overall picture of the concentration of population and employment and the level of spatial variation. Chapter three illustrated the extent to which definitions of sprawl are equated with density. These measures provide a general framework for interpreting the extent of urban sprawl, and are contrasted with the patterns indicated by the more complex measures of sprawl. Understanding the density of the study area is also necessary for full interpretation of the more complex measures; for example the temporal mean growth rate indicates the pace of growth of the outer ring and hinterland compared to the centre but evaluation of the densities is necessary to understand whether certain consequences of sprawl, such as ability to support public transport, are likely to occur. The H^{rel} measure which shows levels of concentration also provides more information in conjunction with density. For instance, homogenous growth in the suburbs would result in an increase in H^{rel}, however, this type of decentralization or outward growth of the city is not necessarily 'urban sprawl' and can also reflect differing patterns of urban sprawl.

All case cities show an above average population and employment density in the urban centre, as shown in Table 5.3, which reflects the strength of European city centres, relative to those in North America. In the outer urban ring and hinterland, Bristol has below average density for both population and employment, and Rennes below average employment density. The remaining case cities however have an above average density in the outer urban ring for both population and employment, although all case cities reflect below average densities in the hinterland. The outer urban ring and hinterland of Bristol also show very similar population and employment densities, while the other case cities show a sharp drop in density in the hinterland, particularly in Helsinki and Rennes, reflecting the rural nature of the hinterland. These density patterns are perhaps indicative of the stronger process of suburbanization in Bristol, and the stronger attractions of the city centres in the other case cities.

Table 5.3: Population and employment density for the six case cities

		Area Km^2	Employment	Population	Employment Density	Population Density
Bristol 1991	*centre*	92	159,151	361,367	1,730	3,928
	outer urban ring	386	87,664	176,245	227	457
	hinterland	868	181,810	393,919	209	454
	total	1,346	428,625	931,531	318	692
Rennes 1999	*centre*	50	110,351	206,229	2,207	4,125
	outer urban ring	559	78,555	158,423	141	283
	hinterland	1,933	39,539	156,536	20	81
	total	2,542	228,445	521,188	90	205
Milan 2001	*centre*	180	678,273	1,182,693	3,768	6,571
	outer urban ring	450	414,991	1,081,160	922	2,403
	hinterland	1,336	486,456	1,343,073	364	1,005
	total	1,966	1,579,720	3,606,926	804	1,835
Suttgart 2000	*centre*	207	349,867	583,874	1,690	2,821
	outer urban ring	759	377,230	852,661	497	1,123
	hinterland	2,687	329,266	1,176,844	123	438
	total	3,653	1,056,363	2,613,379	289	715
Brussels (Population 2001 and Employment 1999)	*centre*	164	578,027	969,079	3,525	5,909
	outer urban ring	1,080	784,129	1,568,838	726	1,453
	hinterland	3,252	350,957	1,375,878	108	423
	total	4,496	1,713,113	3,913,795	381	871
Helsinki 1999	*centre*	63	247,581	233,676	3,930	3,709
	outer urban ring	1,321	369,679	856,924	280	649
	hinterland	14,640	279,686	801,888	19	55
	total	16,024	896,946	1,892,488	56	118

At the small area level shown in Figure 5.1, the employment density of the city centres remains strong. However the more complicated patterns in the outer urban ring and hinterland are revealed. In the Bristol case, the localized sprawl in the North Fringe is evident, along with the concentrations of employment in the Bath and Weston-super-Mare subcentres surrounded by very low density areas in the green belt. In Brussels, the attraction of the city is shown by the higher densities in Brussels and in the outer urban ring, while the pockets of higher density in the hinterland are tied to known growth poles. The employment densities of Helsinki rather than showing a scattered development described in the interviews show an increase in concentration towards the urban centre, with low densities in the rural hinterland. In Milan, high densities are reflected through the urban centre, outer urban ring and hinterland. This is indicative of the sectoral nature of the study area described in chapter four, although lower densities occur to the west and south. Rennes in contrast remains the focus of employment, with employment densities decreasing with distance from Rennes. The pattern of employment density in Stuttgart shows a focus on Stuttgart and the outer urban ring with a drop-off in employment in the hinterland.

Population densities at the small area level shown in Figure 5.2 show a greater spread across the study area than for employment density, except for the case of Helsinki which remains focused on the Helsinki Metropolitan area in the urban centre and outer urban ring. In Bristol, the attractions of Bristol, Weston-super-Mare and the areas to the north of Bristol are evident, with a continuous spread of population between Weston-super-Mare and Bristol. In Brussels, the growth poles are less evident, with Brussels remaining strong and a continuous spread of population around Brussels in the urban centre and to the north in the hinterland. In Milan, an even spread of population around the dominant city of Milan is shown although this is distorted by the sectoral nature of the development zones. In Rennes, the dominance of the city centre and the rural nature of the study area is also evident for population density, although there is a more even spread of low density population in the hinterland than occurs for employment density. Stuttgart reveals a continuous spread of population around Stuttgart with densities dropping off away from the centre. Milan, Stuttgart and Brussels have the most dense population of the case cities, which is reflected by the extent of overspill and level of continuous population around these case cities.

The densities provide some preliminary information on the nature of sprawl with generally, dominant city centres for both population and employment, and more focused concentrations of employment than population. Helsinki and Rennes show a focus of growth on the city centre, set in rural surroundings; Bristol reveals a localized pattern of sprawl with strong sub centres of Bristol and Weston-super-Mare, and Brussels, Milan and Stuttgart show a continuous spread of population across their study areas. Findings from the interviews highlight Bristol as showing a typical pattern of North American sprawl, and while this is true at the local level, at the regional scale, development is concentrated. It is the cities of Brussels, Stuttgart and Milan which show a greater 'sprawl' across the region, despite the interviewees describing these cities as much more European with strong city centres.

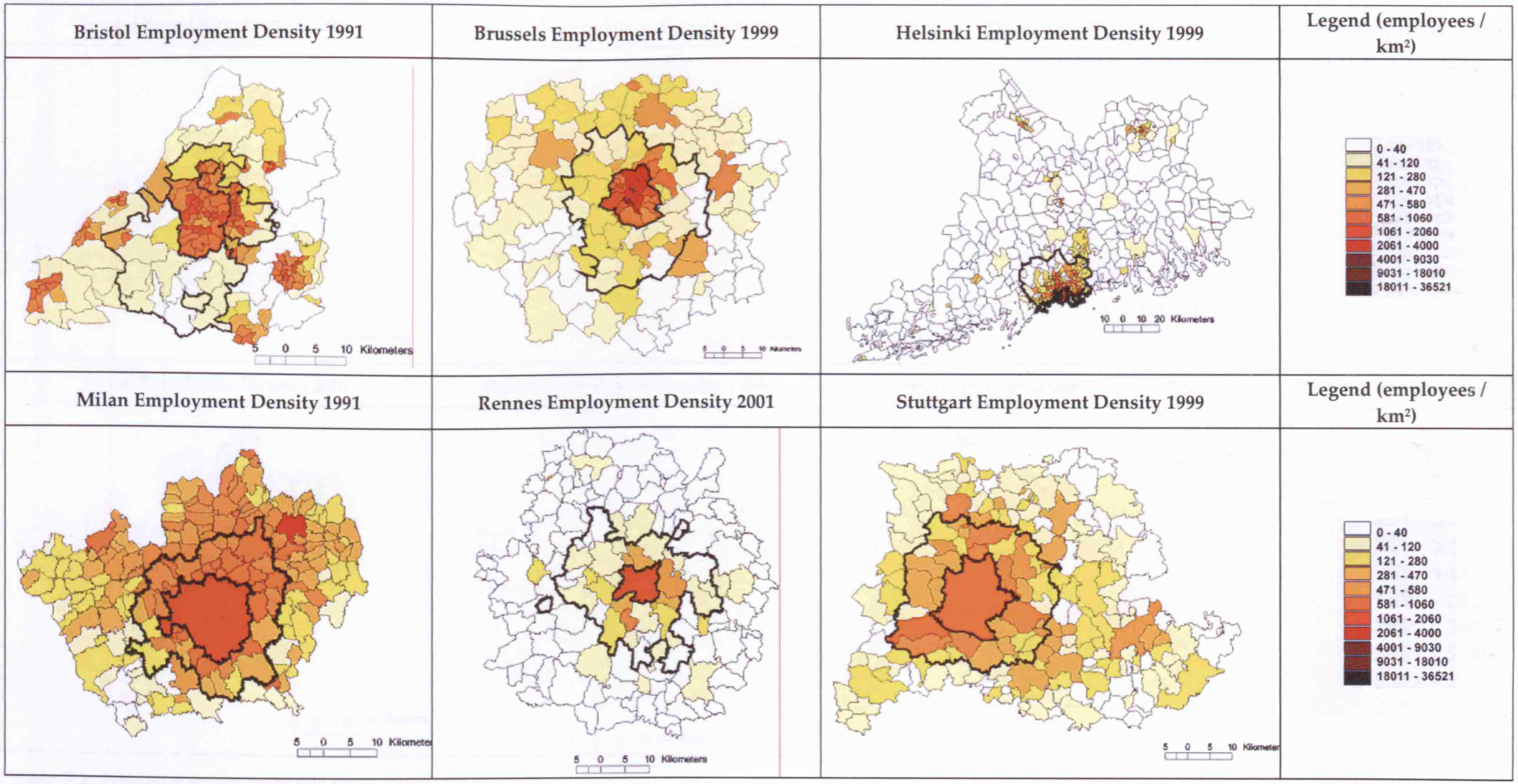


Figure 5.1: Employment density in the case cities

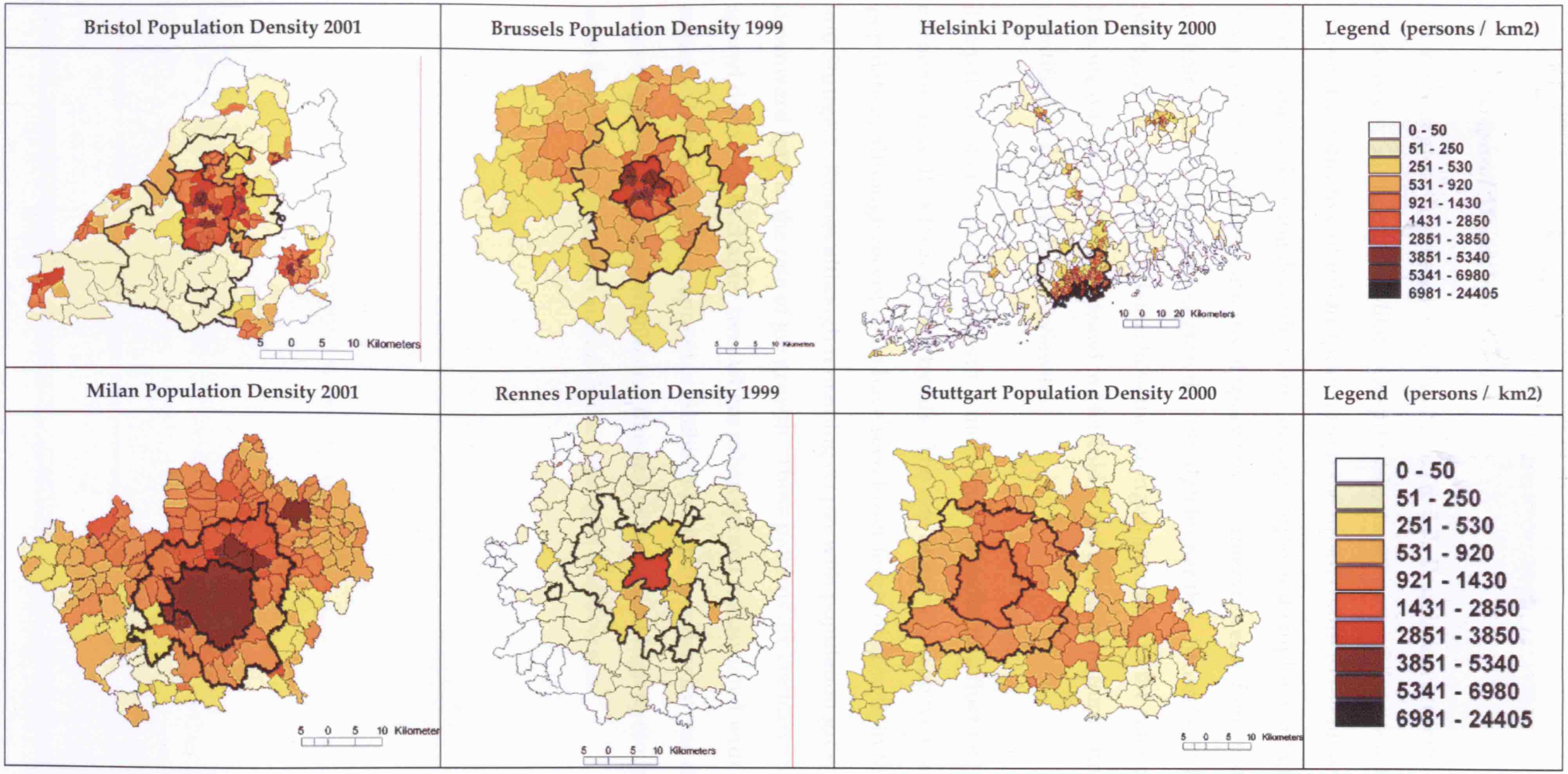


Figure 5.2: Population density in the case cities

5.2.1 *Temporal Mean Growth Rate*

The rates of growth are shown in Figures 5.3 to 5.7. Population growth is low or stable for Brussels, Stuttgart and Milan. Despite this, these cities exhibit a widespread pattern of growth, indicative of urban sprawl, from the urban centre to the hinterland. Indeed, Milan despite showing declining rates of population and employment growth is still perceived as exhibiting patterns of sprawl by the interviewees. Rennes also shows declining rates of population growth, although higher than Brussels, Milan and Stuttgart. Helsinki and Bristol show the strongest increases in the rates of population. Despite this the pattern of sprawl in Helsinki is not the most extreme, nor is it identified as such by the interviewees.

The pattern of employment growth is more variable, reflecting fluctuations in the economy as well as local growth trends. The rate of growth is above that for population, although recent years have seen lower levels of growth in Milan, Helsinki, and Stuttgart. Rennes although remaining on par with population growth has seen a downward turn in the rate of job growth. These patterns are contrary to definitions of sprawl described in chapter two, where urban sprawl is associated with fast growing regions. In the case cities, sprawl is exhibited in the lower density case cities with high rates of growth, such as Helsinki and Rennes, or in areas of high to moderate density with lower rates of growth such as Milan, Stuttgart and Brussels.

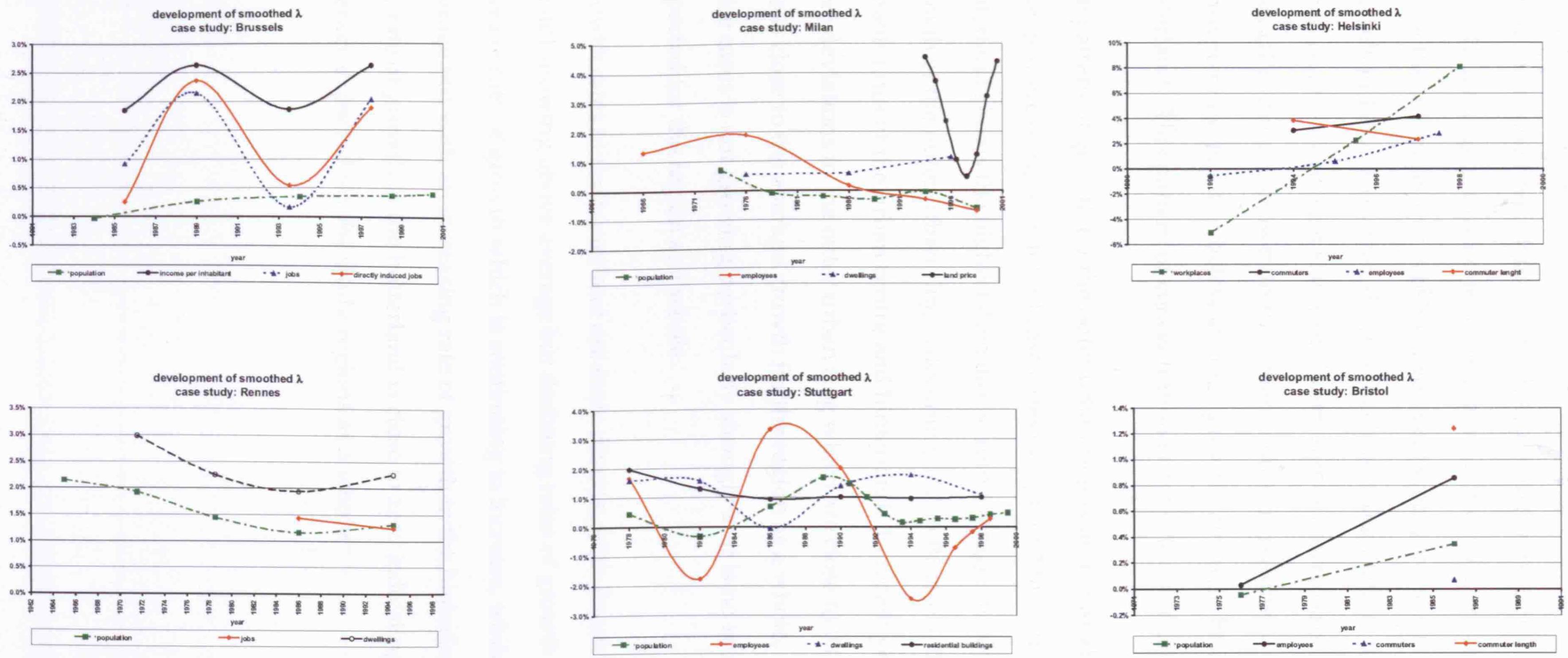


Figure 5.3: Temporal mean growth rate for the case cities

The spatial patterns of population growth in Figures 5.4 and 5.5 show the extent to which each zone (the urban centre, the outer urban ring and the hinterland) deviate from the average growth rate of the region as a whole. In all case cities, the growth rate of the urban centres is below average, except for the above average growth rate of Brussels in 1999. However, despite this loss of population, the growth rates of the urban centres have been stable or shown signs of increasing. Helsinki shows an unusual pattern of growth in the urban centre, increasing to 0.4 percent in 1995 before subsequent decline to a below average growth rate, with below average rates in the hinterland. This pattern of concentration is not evident in any other case city.

The pattern of growth for the outer urban ring is more variable, although this is the strongest growing zone for all case cities except for Milan and Stuttgart, for which the hinterland shows the highest deviations from average. In all case cities, the rate of growth of the outer urban ring is declining and in Brussels, this has converged with the growth rates of the urban centre and hinterland. In recent years, Milan and Stuttgart have deviations in the outer urban ring which are close to 0.0 percent, indicating that this is close to the average growth for the region as a whole. The outer urban ring in these cases is not growing particularly strongly as it is no more than the level of growth expected for the region as a whole.

Growth rates in the hinterland are more diverse, with Brussels, Rennes, Stuttgart and Bristol showing above average but declining rates of growth. Milan shows an above average rate of growth which is continuing to increase, while Helsinki shows a below average but with an increasing rate of growth in the hinterland. In Rennes and Bristol, the rate of growth in the hinterland is close to zero indicating that this is close to the average expected for the study regions as a whole.

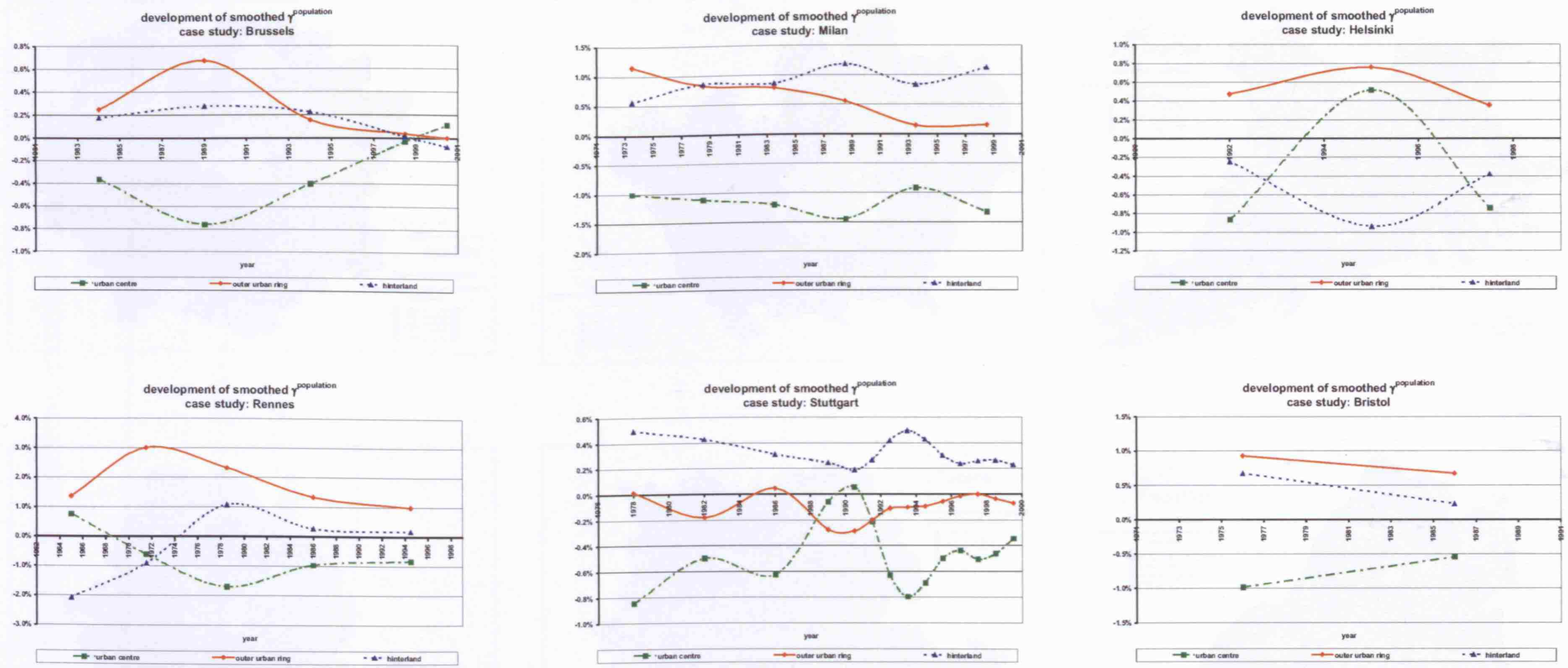


Figure 5.4: Temporal mean growth rate for population by zone in the case cities

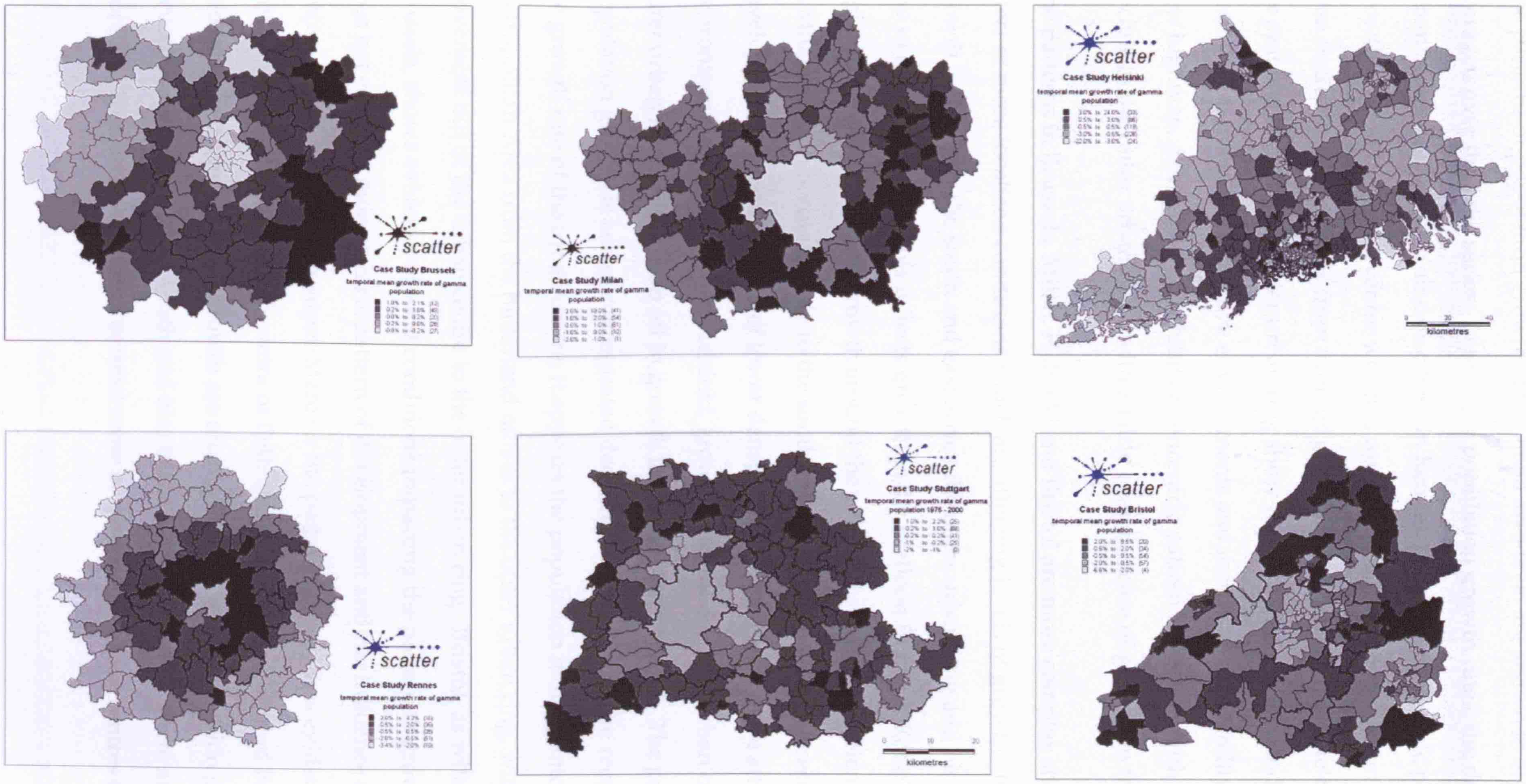


Figure 5.5: Temporal mean growth rate for population by small area in the case cities

The patterns of population growth at the small area level are shown in Figure 5.5 averaged over the time series. In terms of population growth rates, the decline in the urban centre is evident in all case cities. In Rennes, there is a concentric pattern of growth around the urban centre which is concentrated in the outer urban ring, with an even decrease in deviations from average growth in the hinterland. The communes in the east and north of the outer urban ring show the strongest growth, and these are areas with particularly attractive environments and increased accessibility through a new highway. Stuttgart also exhibits a concentric pattern of growth with an even decline in the outer urban ring , with a fairly even increase of growth in the hinterland.

The patterns in Brussels, Milan, Helsinki and Bristol are more complex showing the effect of more localized conditions which are affecting levels of growth. In Brussels, growth is strong to the south and east across the outer urban ring and hinterland, and low to the north west. This reflects growth in the Walloon Brabant, Rotselaar and Silly region. There is also strong growth around the cities of Leuven, Mechelen and Wavre. In Milan, growth occurs mainly to the south and east – these are more recently developed zones, and are also of lower density, thus providing a more attractive environment for relocation. In Helsinki, growth is focused on the urban centre and the outer urban ring, with a drop off in growth in the rural hinterland. The pattern of population growth is one of concentrated deconcentration. Given the recent decline in the growth rate of the urban centre, it appears the population moving into the Helsinki Metropolitan Area from the hinterland moves to the outer urban ring, with additional movement out of the urban centre to the outer urban ring. Bristol, as with Milan and Brussels, shows evidence of local conditions impacting the pattern of growth. Bristol does not exhibit a monocentric pattern of development and the influence of the sub centres of Bath and Weston-super-Mare on the pattern of growth is evident. Low growth rates in Bristol, the sub centre of Bath and the green belt around Bath are evident. The areas of higher growth are much patchier, with population growth focused between Bristol and Bath and also to the north of Bristol. There are however more localized areas of growth around some of the smaller urban centres such as Yate /

Chipping Sodbury, Kingswood and Thornbury in South Gloucestershire, and Clevedon, Nailsea, Yatton and Backwell in North Somerset.

The trend in the case cities is towards population decline in the urban centre which has recently stabilized. Apart from this, the patterns of growth are more varied. There is a tendency for growth to remain close to the urban centre, with the majority of growth occurring in the outer urban ring in Bristol, Helsinki, Rennes and until recently in Brussels. However, in Milan, Stuttgart and in recent years Brussels, most growth has been concentrated in the hinterland showing a more extensive spread of growth and lower levels of growth close to the city centre. While population growth is decreasing in the city centre, the spread of population and the extent of concentration varies for the case cities.

The pattern of growth of employment, shown in Figure 5.6 for the case cities is more varied than that for population as it is also influenced by national economic trends. The rate of employment growth is below average in all urban centres, except for Helsinki, which shows an above average growth of employment. Despite the below average growth the rate of employment growth is stable or increasing, in all cases. This is similar to the patterns of growth shown for population growth in the urban centre. Above average levels of growth are found in the outer urban ring, although Milan in recent years exhibits a below average level of growth. Growth rates in the outer urban ring are declining in Bristol, Rennes, Milan, and Stuttgart, with stable growth rates in Helsinki. In Brussels, the outer urban ring is increasing in the level of employment growth.

In the hinterland, growth rates vary with generally above average rates in Brussels, Milan, Stuttgart and Bristol. Growth rates are below average in Helsinki and in Rennes – although this has shown a strong increase and in recent years shows little deviation from the average . The growth rates in the hinterland are declining although there has been a recent upturn in Milan and strong fluctuations in Stuttgart. In general as with population, the outer urban ring and the hinterland have the highest levels of employment growth, although the urban centre has been holding its own with increasing or stable rates of employment growth. In the more rural case cities such as Helsinki and Rennes, and in Bristol which contains large areas of undeveloped land in the hinterland, the growth rates are highest in the outer urban ring. This is also the case for Brussels although it contains strong growth poles in the hinterland. In Stuttgart and Milan, growth is more diffuse with stronger growth rates in the hinterland than in the outer urban ring.

At the local level shown in Figure 5.7 variations are evident within each zone. In Helsinki, a similar pattern to that of population growth is evident where employment growth is focused around Helsinki with much lower growth rates in the hinterland. In Rennes, growth is also focused in the outer urban ring around Rennes, although it is concentrated to the north rather than distributed concentrically around the urban centre. In Stuttgart, Milan, Bristol, and Brussels, employment growth extends outward from the urban centre. In Stuttgart, this is fairly evenly spread from the outer urban ring to the hinterland, with lower rates of growth in the south east. In Brussels, growth of employment is dominant towards the east with a strong focus around the growth poles. In Milan, employment growth is focused to the east and south as with population growth. In Bristol, the growth of employees is much more evenly spread across the outer urban ring and hinterland apart from the sub centre of Bath where growth is declining.

In terms of patterns of population and employment growth European cities do not exhibit the strong growth rates described in the US literature, and the problems of urban sprawl occur even without an exponential decline in density to the hinterland. While all case cities show lower than average growth in the urban centre, growth varies in strength between the outer urban ring and the hinterland among the case cities. The urban centre, despite lower than average growth rates does not exhibit the 'hole in the doughnut' phenomenon of North American sprawl, as growth rates show signs of increase or are stable. Despite this variance in growth between the outer urban ring and the hinterland, similar patterns of movement from the centre to the outer urban area are described in the previous interviews described in chapter four.

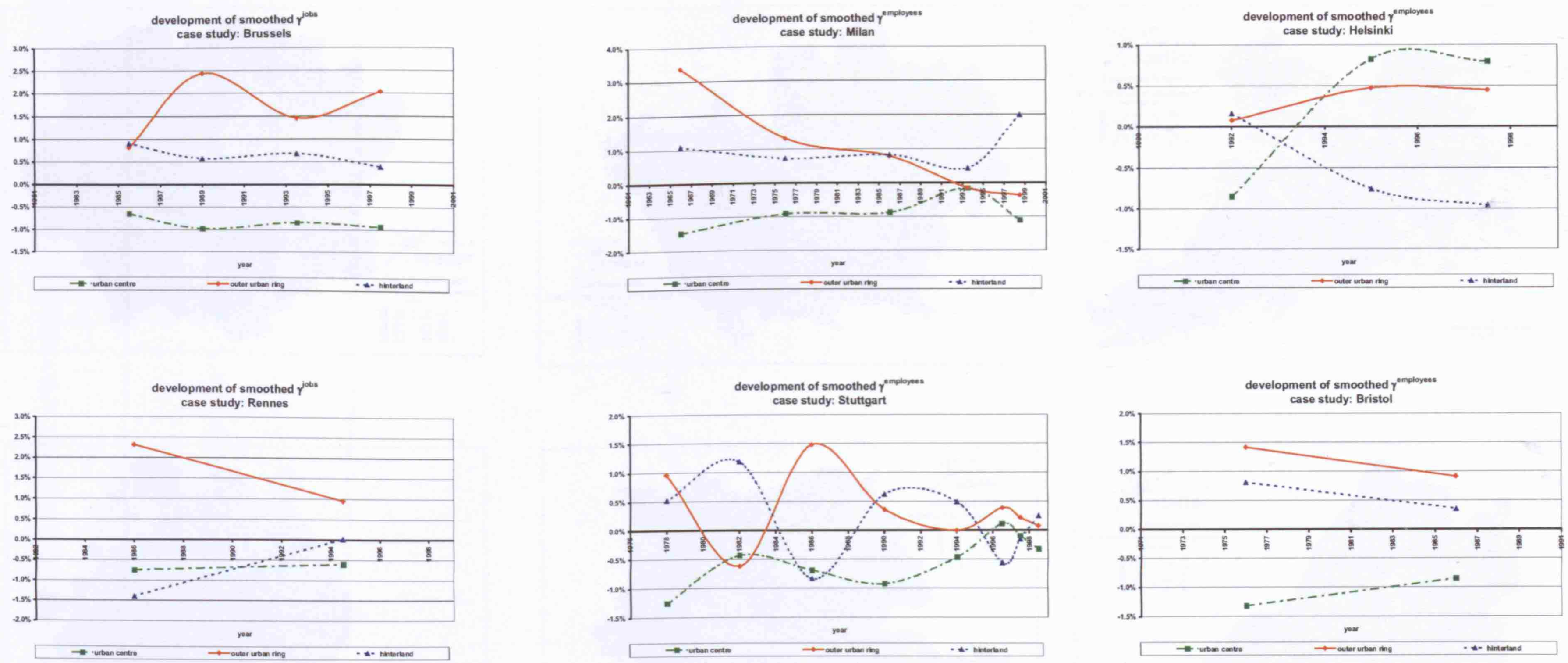


Figure 5.6: Temporal mean growth rate of employment by zone in the case cities

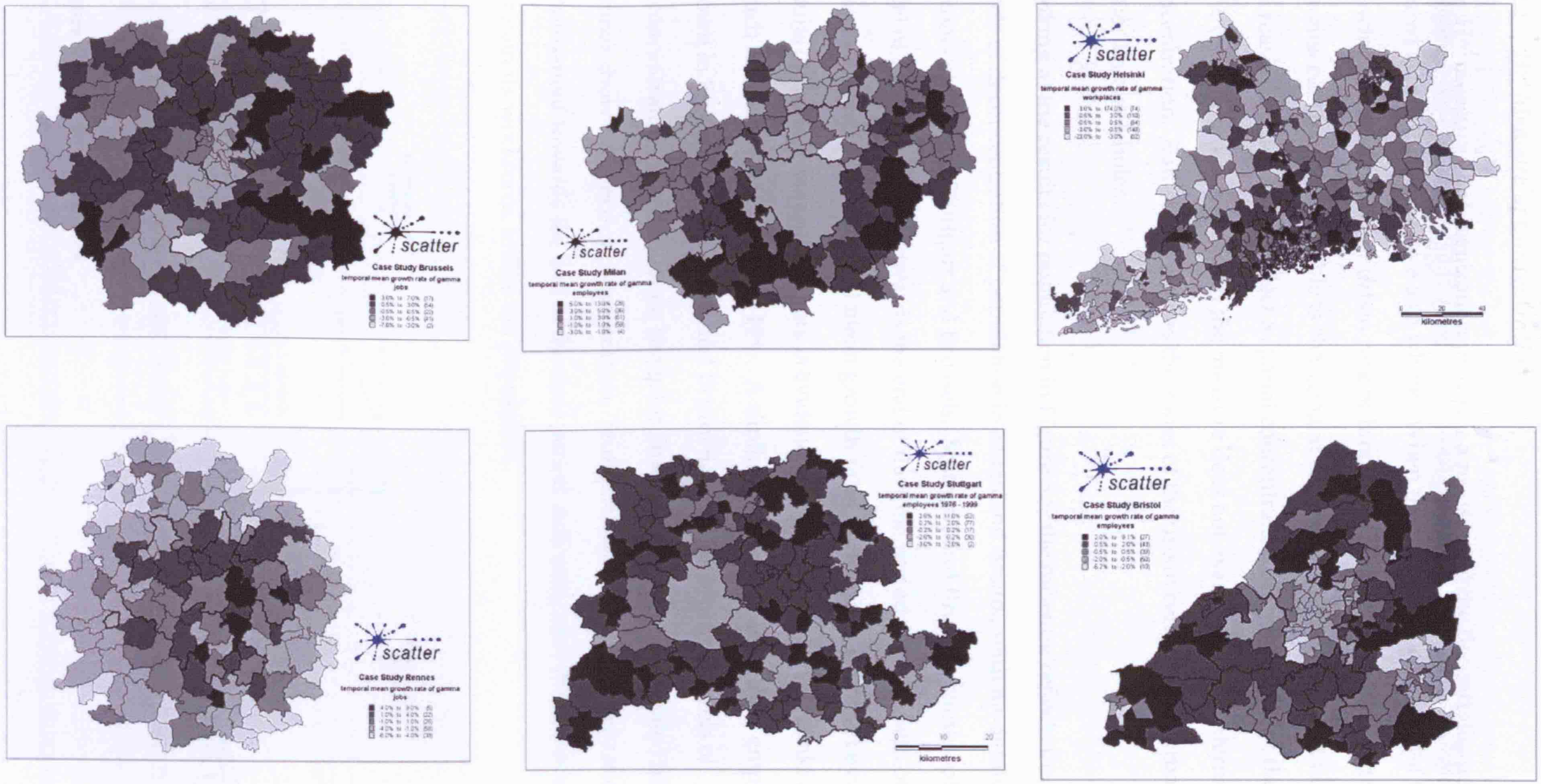
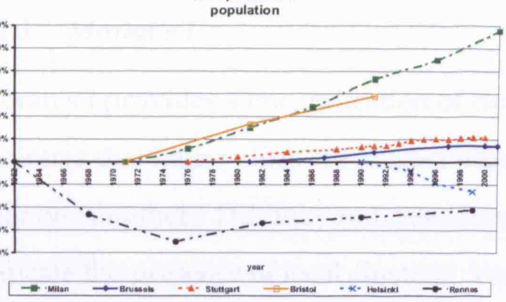


Figure 5.7: Temporal mean growth rate of employment by small area in the case cities

5.2.2 H^{rel} *Measure of Concentration*

The H^{rel} measure of concentration provides a measure of the decentralisation of urban sprawl across the study area as a whole. When the measure increases, the variable is growing faster in the outer urban ring or hinterland than in the urban centre. When it remains constant, the variable is changing at a constant rate across the study area. Decreasing values of H^{rel} reflect a spatial concentration of the variable at the urban centre. It should be noted that the measure does not examine local patterns of concentration. Rather it examines the zones of the urban centre, outer urban ring and hinterland as wholes.

Looking at the results for population in Figure 5.8, the measure reflects the highest levels of deconcentration of population in Milan and Bristol, with moderate deconcentration in Stuttgart and Brussels. Stuttgart and Brussels show a plateau in the level of deconcentration towards the end of the time period. The growth of the urban centre evident in the temporal mean growth rates for Brussels is not yet evident in the results of the H^{rel} measure. There is evidence of concentration in Helsinki and Rennes which have declining values of H^{rel}. A similar pattern is observed for employment, as shown in Figure 5.8, with Milan and Bristol having the strongest levels of deconcentration, with moderate levels for Stuttgart and Brussels, while Helsinki and Rennes show evidence of concentration. Stuttgart shows some concentration of employment towards the end of the time period indicating that the urban centre is able to retain its workforce, unlike the population.



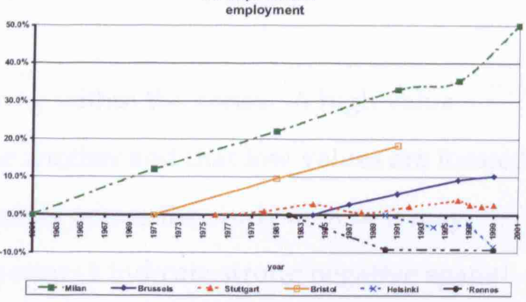


Figure 5.8: H^{rel} for the case cities

Milan and Bristol have similar levels of H^{rel} for population. However, the densities across the study area are very different. Bristol has a pattern of clusters of high density among low densities in the outer urban ring and hinterland, while Milan has a much more diffuse spread of high to moderate density across the study region. Despite the similar levels of concentration shown by the measure the pattern of density indicates a somewhat different pattern of urban sprawl. Likewise for employment Brussels has a higher H^{rel} than Stuttgart. However the pattern of density indicates a more focused pattern of concentration in Brussels, with employment clustering around the growth poles in the hinterland, while in Stuttgart ,employment is evenly spread across the study region. The zonal nature of the H measure masks important variations within each zone, which limits its ability to detect patterns of urban sprawl.

The patterns of the H^{rel} measure are not entirely consistent with those of the temporal mean growth rate. For Helsinki and Rennes, the evidence of concentration is in accordance with the lower levels of growth in the hinterland and the focus of growth around the urban centre. Milan and Bristol also show strong evidence of growth across the study region which matches the process shown by the H^{rel}. In Brussels and Stuttgart, despite a pattern of temporal urban growth across the outer urban ring and hinterland, H^{rel} is only moderate, and in Stuttgart shows signs of concentration in recent years. In Milan, a similar pattern of temporal urban growth is evident but the H^{rel} has a much stronger increase. The case cities with the most diffuse growth, as indicated by the temporal mean growth rate, do not in all cases show a strong pattern of deconcentration.

5.2.3 *Moran's I*

Moran's I provides some indication of clustering within the zones. A high value indicates that high values are located near one another and that low values are located near one another. This may indicate homogeneity across the study area or it may indicate the presence of local clusters. Values near -1 indicate strong negative spatial autocorrelation – high values tend to be located near low values, which in this case indicates a heterogeneous landscape. Values near zero indicate random development.

The Local Moran's I indicates the points of local clusters, unlike the global statistics which indicate any deviations from a random pattern. When a global test finds no deviation from randomness, the local test can uncover isolated hotspots of higher values. When a global test does detect clustering (values near +1), local statistics can help to determine whether the study area is relatively homogenous in that local statistics are similar throughout the area, or whether there are local outliers that contribute to the global pattern. The Local Moran's I reflects the level of spatial autocorrelation around each small area. The values are relative to adjacent neighbours so high or low clusters are a function of the neighbourhood, rather than of the scale of the region as a whole.

In Brussels, as shown in Figures 5.10 to 5.12 there is a moderate level of spatial autocorrelation for both population and jobs, with little change over the time period. The pattern of spatial autocorrelation occurs in concentric rings – with positive spatial autocorrelation located in the urban centre. This reflects dense values in the urban centre located near to each other showing a homogeneous pattern of growth. The outer urban ring show negative levels of spatial autocorrelation, with high values located near to low values, indicating a heterogeneous area of population density. The hinterland shows levels of Moran's I which are close to zero, indicating no spatial pattern. Some of the growth poles such as Leuven and Michelen show negative spatial autocorrelation as the density is higher than the surrounding area. The pattern of spatial autocorrelation for economic growth is similar, with the growth poles of Leuven and Michelen having higher densities than the surrounding area, resulting in negative spatial autocorrelation.

There is very little change in Global Moran's I over the time period for population density, as shown in Figure 5.9. The change that has occurred is fairly even over the outer urban ring and hinterland, while the urban centre has seen a small increase in the value of Moran's I over the time period. The change in Moran's I for jobs is less even as shown in Figure 5.9. The urban centre has increased in homogeneity between

1984 and 1999. Changes in the outer urban ring and hinterland are fairly similar to the west of the study region with almost no change in Moran's I, while the zones to the east have increased slightly.

In Milan, Moran's I for population shows a moderate level of spatial autocorrelation with some increase over the period as shown in Figure 5.9. There is a low value of spatial autocorrelation for employees with a further decrease after 1990. Looking at the Local Moran's I for population, as shown in Figure 5.10 shows that development is much more varied over the region than for Brussels. The eastern and western edges of the study area and the area north of Milan show moderate levels of positive spatial autocorrelation indicating a homogeneous pattern of growth. The ring around Milan, which however does not correspond to the boundaries of the outer urban ring, shows negative spatial autocorrelation or almost no spatial autocorrelation. Although the pattern is more varied than in Brussels, as in that case, it is the area just beyond the urban centre which shows the greatest heterogeneity – perhaps indicating varying levels of development in an area of transition.

A similar pattern is observed for employment, as shown in Figure 5.12 although the zones adjacent to the Milan urban centre show more evidence of positive spatial autocorrelation. Looking at change over the period for population, as shown in Figure 5.11 there has been an increase in Moran's I in the urban centre, a decrease in spatial autocorrelation in the western and eastern edges and to the north of Milan. The remaining areas show almost no variation in Moran's I over the time period. The pattern of change for employment, as shown in Figure 5.13 shows a decrease in Moran's I in the urban centre, and large decreases in Moran's I to the west of the study area. The rest of the study area shows an increase in Moran's I – or increasing homogeneity.

In Stuttgart, Global Moran's I for population shows a moderate level of spatial autocorrelation over the time period with little variation, as shown in Figure 5.9. The value for employment shows a lower level of spatial autocorrelation, but one which is increasing over the time period. The local pattern of spatial autocorrelation for population, as shown in Figure 5.10 shows zones with high spatial autocorrelation around the urban centre and on the eastern edge of the study region in the rural part of the hinterland. Intermediate areas show negative or low spatial autocorrelation. The pattern of spatial autocorrelation for employment is more varied, as shown in Figure 5.12 while the areas around the centre and to the east tend to have higher levels of spatial autocorrelation, this is more fragmented. The change in spatial autocorrelation for population, as shown in Figure 5.11, over the period indicates that the areas of the urban centre and outer urban ring have increased in the level of spatial autocorrelation, while the areas to the east have decreased. The changes in spatial autocorrelation for employment, as shown in Figure 5.14 show a more varied pattern, with decreases in autocorrelation to the east of the study region.

The Helsinki study area has a low level of global spatial autocorrelation for both population and workplaces which remains stable over the period, as shown in Figure 5.9. The local distribution of spatial autocorrelation for population, as shown in Figure 5.10 shows high levels of spatial autocorrelation in the urban centre, with negative autocorrelation in the outer urban ring and moderate or random patterns in the hinterland. The pattern is similar for workplaces, as shown in Figure 5.12 although the area of negative autocorrelation is smaller and lies closer to the urban centre. As in the case of Brussels, Milan, and Stuttgart a zone of mixed high and low values can be found around the urban centre, implying an extension of development into less dense areas. There is almost no change over the time period for either population or workplaces, as shown in Figures 5.11 and 5.13 with a small amount of change near the urban centre.

In Rennes, the level of spatial autocorrelation is close to zero, indicating an almost random pattern, as shown in Figure 5.9. This has increased marginally over the period but remains low. The local pattern shows some homogeneity around the city centre for population and employment, as shown in Figures 5.10 and 5.12 although this is spread over a wider area for population. Apart from this the rest of the area shows no pattern of development. The pattern of change over the time period for population and employment is low with some decrease around the urban centre, as shown in Figures 5.11 and 5.13.

The Bristol study area has a low but constant Global Moran's I, as shown in Figure 5.9. Spatial autocorrelation is highest in the urban centre for both population and employment, as shown in Figures 5.10 and 5.12 although interestingly it is around zero for both Bath and Weston-super-Mare, indicating a random pattern in these areas. There is a negative level of spatial autocorrelation around Bristol, stretching west towards Weston-super-Mare indicating a moderate level of heterogeneous development. The pattern of negative autocorrelation around the urban centre is not as strong as in the other case cities.

The patterns of local spatial autocorrelation are not consistent across the case cities. However, there is a tendency for higher levels of heterogeneity around the urban centre perhaps indicating the area with the most transition. Employment patterns tend to be more varied than those for population as a result of national variations. In terms of change over time, the urban centres show the most change in Local Moran's I but apart from this, the pattern of change varies between case cities. For example, cities such as Rennes and Brussels show almost no change over time while others such as Milan are much more dynamic. This is related to the changes in population and employment growth over the time period shown in Figure 5.11 and 5.13 although the pattern is distorted as this refers to change over the entire zone rather than to local neighbourhood changes.

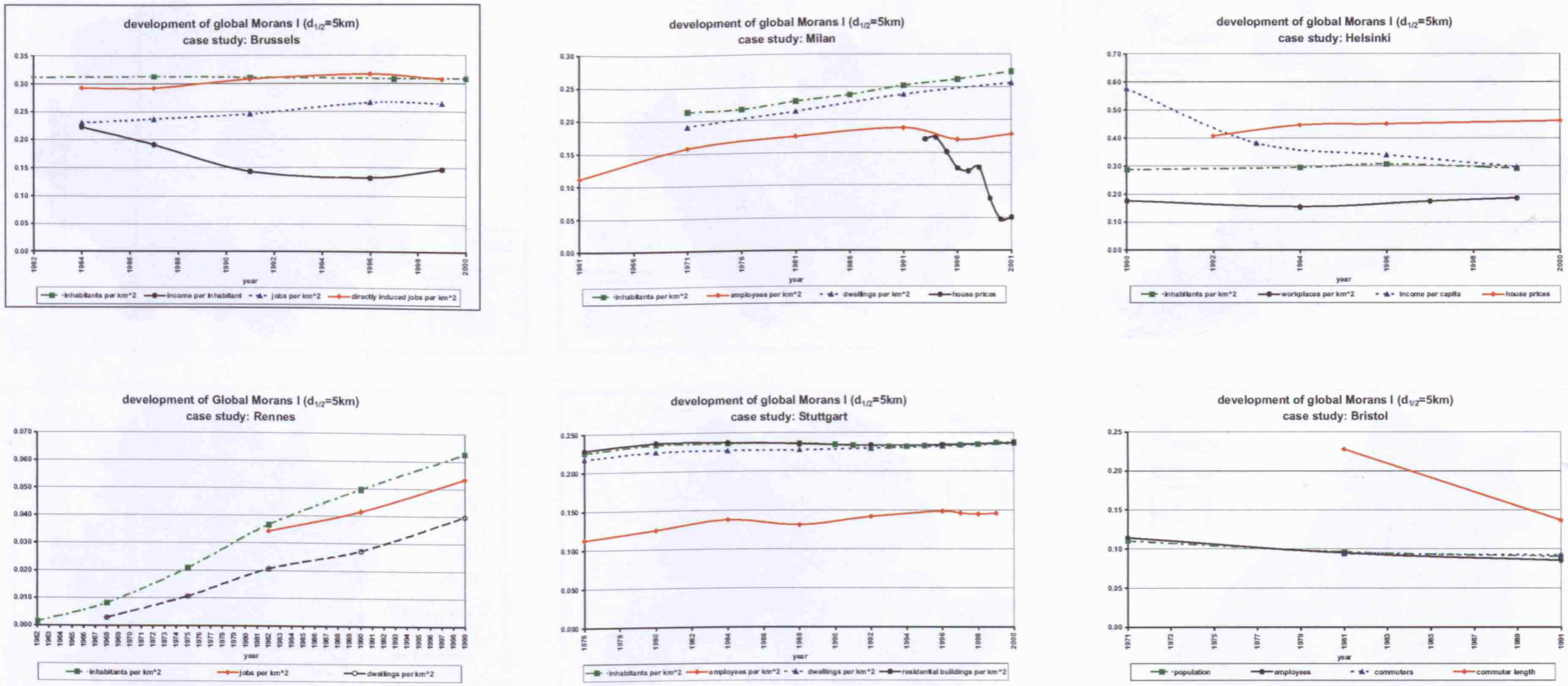


Figure 5.9: Global Moran's I for the case cities

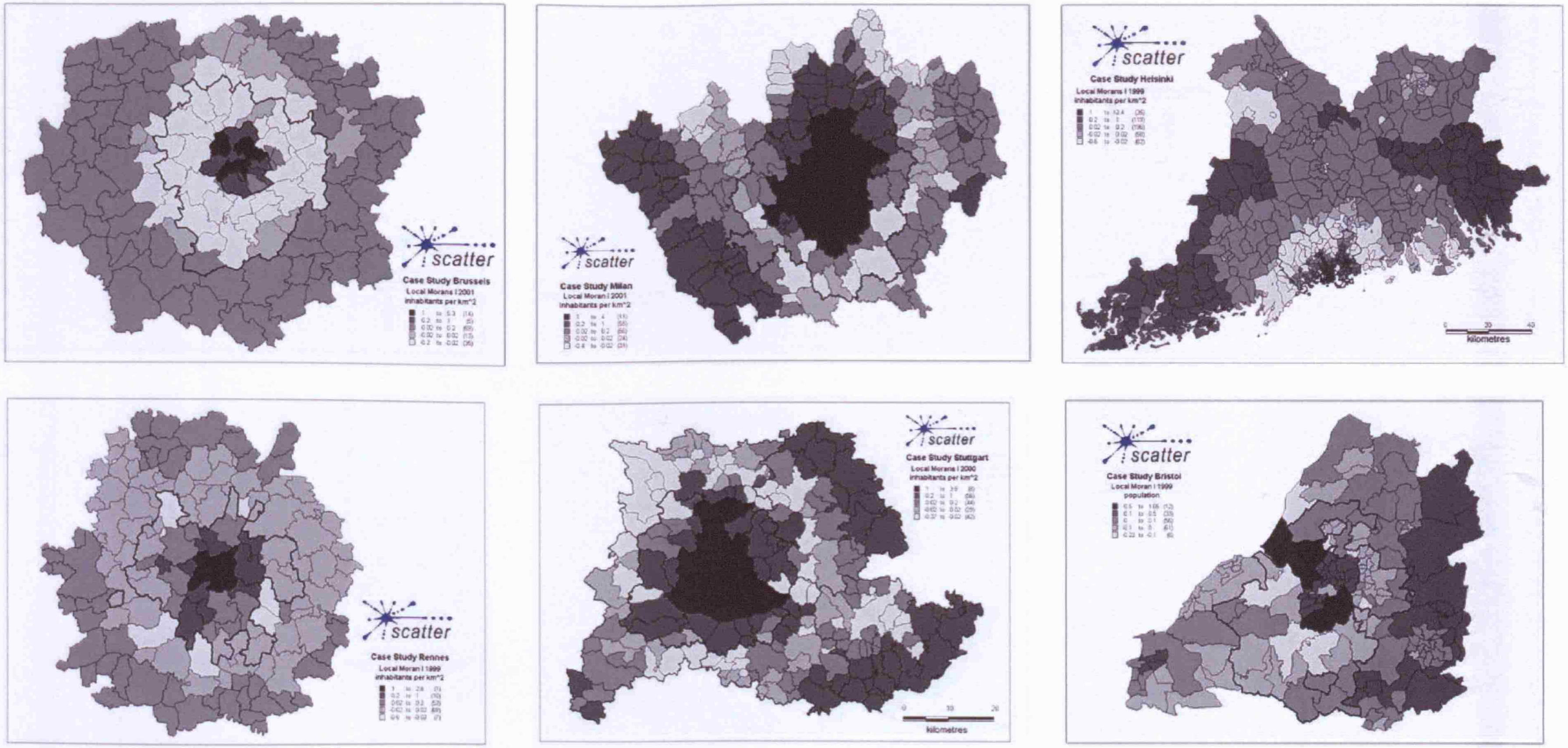


Figure 5.10: Local Moran's I for population in the case cities

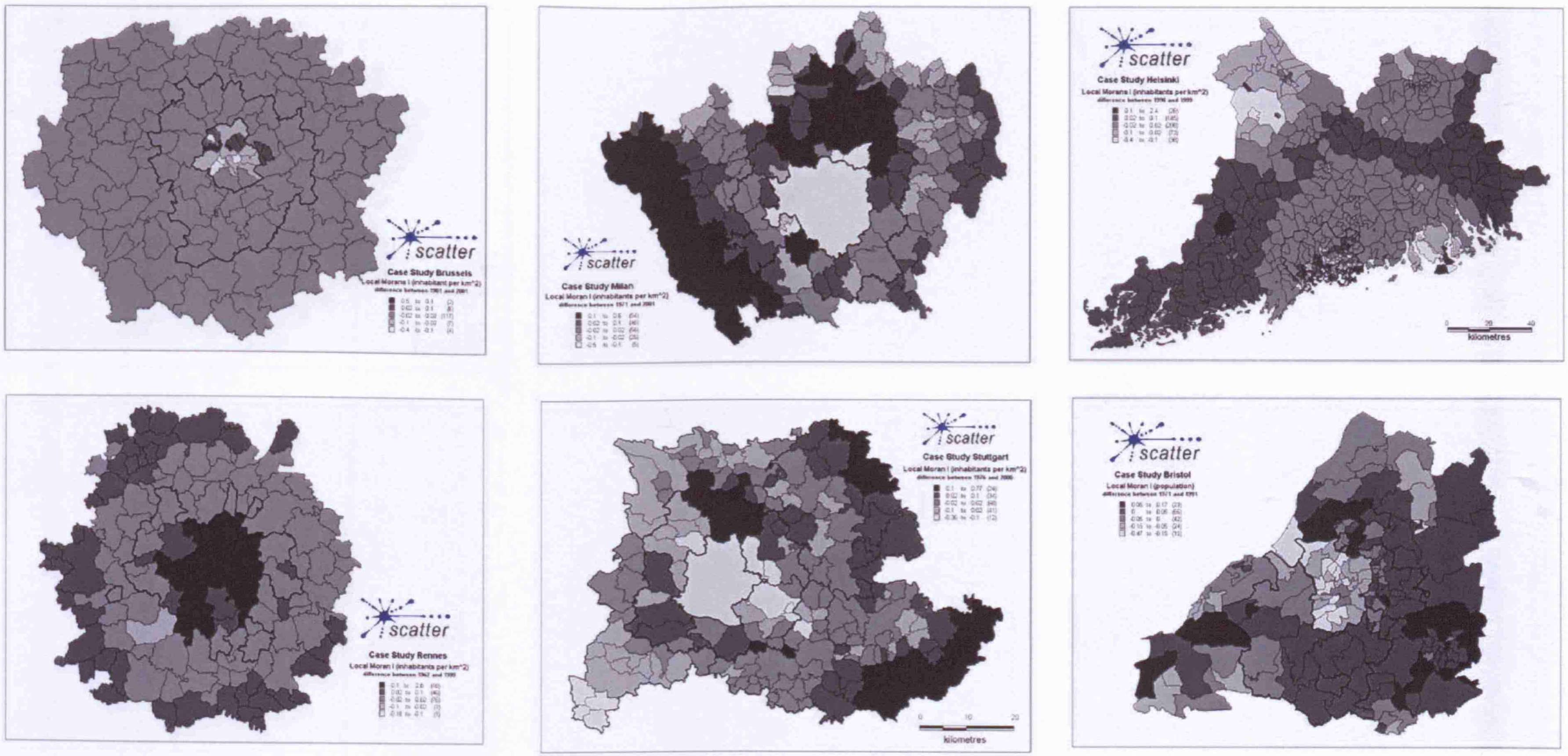


Figure 5.11: Change in Local Moran's I for population in the case cities

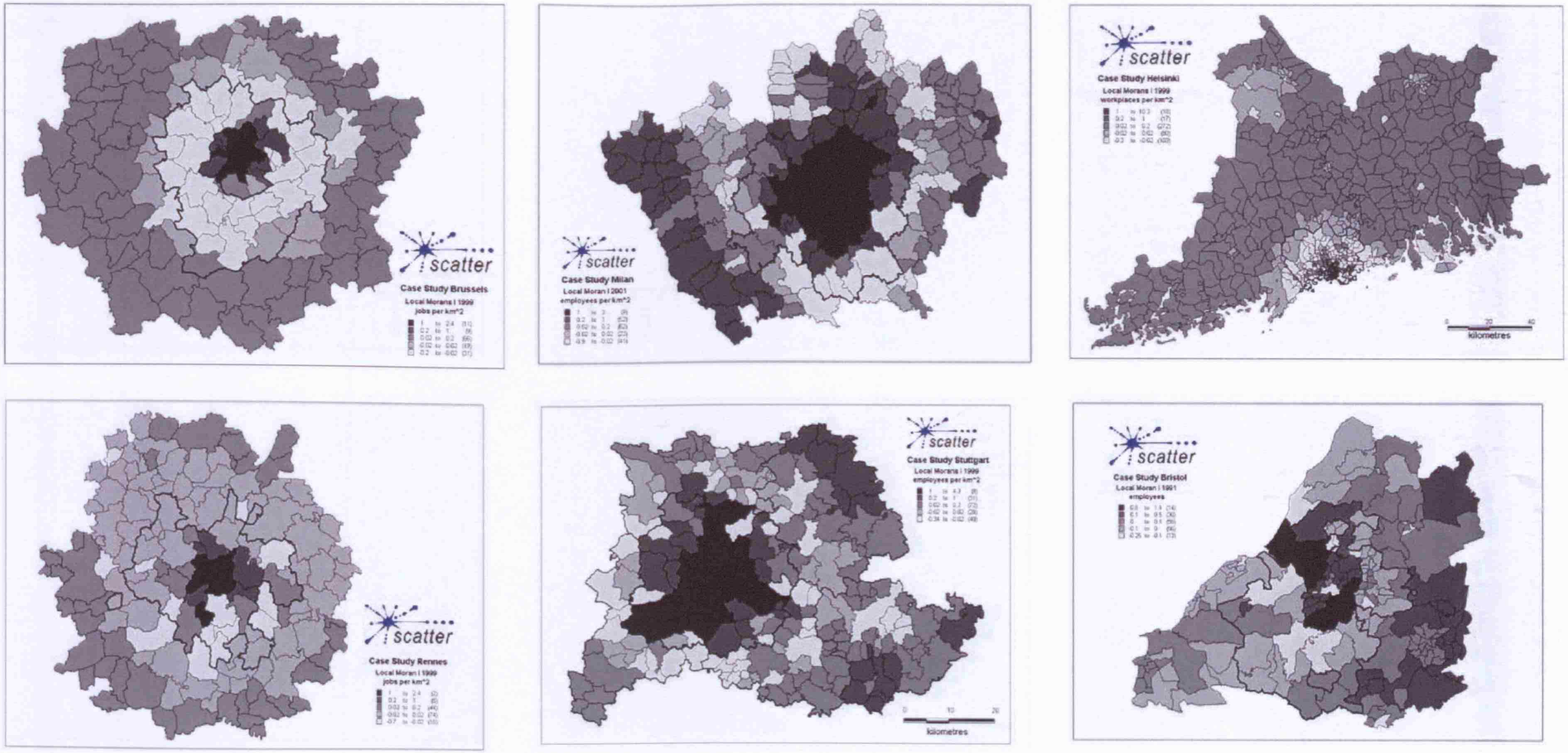


Figure 5.12: Local Moran's I for employment in the case cities

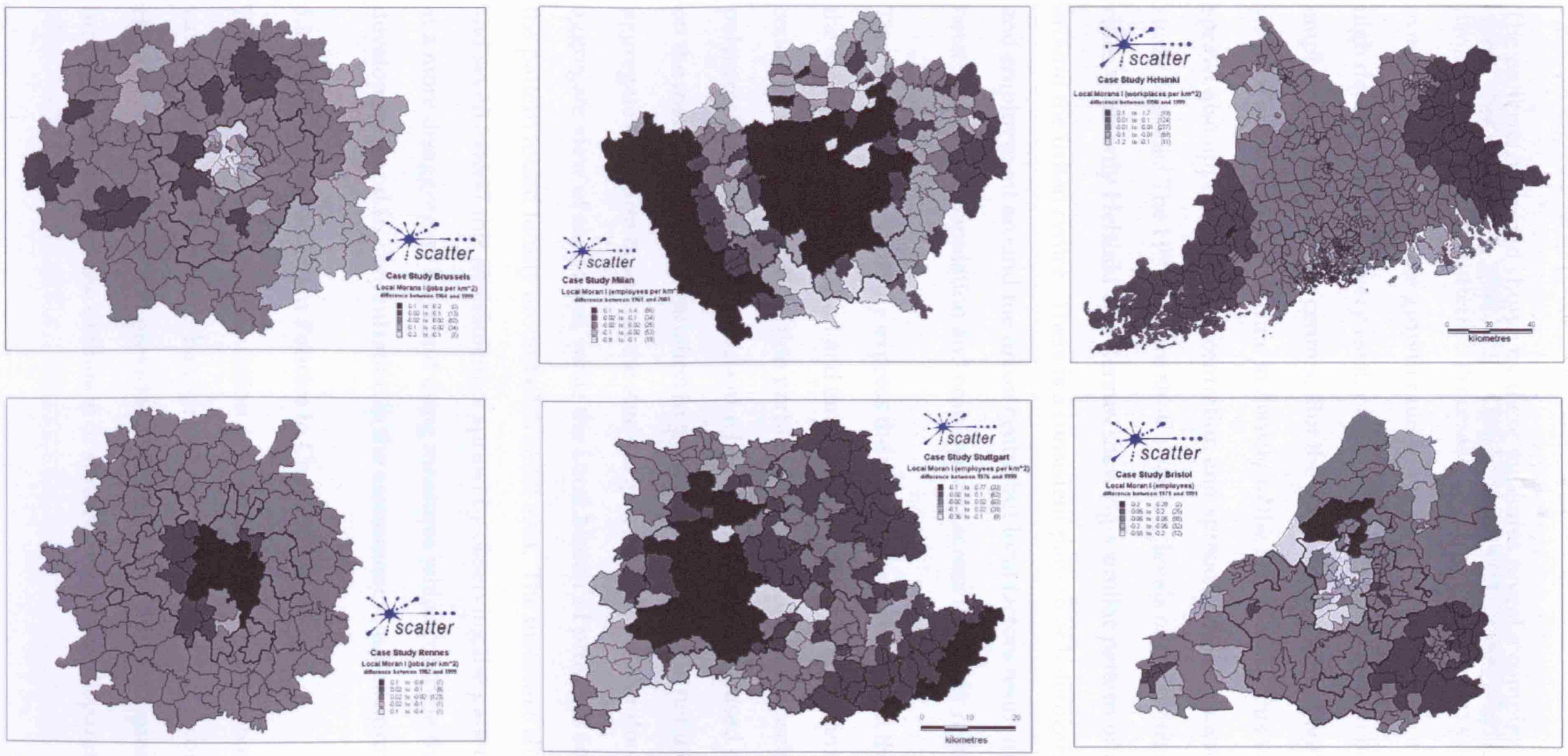


Figure 5.13: Change in Local Moran's I for employment in the case cities

5.2.4 *Summary of SCATTER Measures of Sprawl*

The patterns of sprawl shown by these measures reveal a complex interplay of densities and growth patterns. Processes associated with urban sprawl are present even with only moderate growth rates in the case cities. There is a consistent pattern of high density and at the very least, of stable growth rates for both population and employment in the urban centres. But the problems associated with sprawl occur even without an exponential decline in density to the hinterland. This variety of patterns of sprawl also applies to the concentration and spread of development across the case study regions. The H^{rel} measure shows varying levels of concentration for the case cities, with only Helsinki and Rennes showing a similar pattern of concentration around the urban centre. There is a consistent pattern of heterogeneity in population and employment around the urban centre but local factors result in variations in heterogeneity of population and employment across the study regions.

The measures only partially express the picture of sprawl in that they do not combine the assessment of population and employment density with patterns of spread or concentration; there is distortion particularly in Bristol and Brussels where a more polycentric urban pattern is present while the measures are based on the zones focused on the main centre; local variation in the pattern of sprawl is not indicated by the more aggregate measures based on the study region as a whole. Nor does it provide an aggregate view of each zone, while the Local Moran's I provides an indication only of the pattern found locally around each small area. The measures shown in chapters six and seven extend this assessment of sprawl by observing the patterns of development at a more disaggregate level and using measures which combine the density of development and its concentration in the assessment of urban sprawl.

5.3 Simulation of Urban Policies to Combat Sprawl

This section examines the simulation of common policies to combat sprawl. Given the variation in the patterns of urban sprawl across the case cities, a comparison of the effectiveness of the policies provides an indication of the consequences of sprawl and further clarification on the definition of sprawl under such disparate urban forms. The focus in Europe has traditionally been on the use of policies with a land use dimension. Policies with wide-spread acceptance focus on the concept of the compact city and related land use planning policies discussed earlier in chapter three.

While there is debate over the attainability of the ideal of the compact city focused around a single centre, there is an increasing consensus that some form of targeted development is the key to containment of urban sprawl, most often discussed in ideas of decentralized concentration and settlements around transport corridors. These policies are supported by less comprehensive policies of containment such as green belts and urban growth boundaries.

In contrast to the regulatory policies applied to European cities with strong planning and regulatory structures, tools typically used to control sprawl in North America focus on fiscal incentives. These relatively weak planning systems emphasize control through the market, using fiscal measures and demand-led strategies. The measures of new urbanism, and cluster zoning are the primary measures discussed in the literature to cut land consumption, but have had little success in preventing urban sprawl. Traditional land use policies to combat sprawl are well established in Europe and widely discussed in the literature. However, fiscal policies and demand-led strategies are less widely tested in Europe. The simulations here examine the ability of such policies to combat sprawl in three of the case cities: Stuttgart, Brussels and Helsinki.

5.3.1 Land Use Policies to Combat Sprawl

Policies to combat sprawl have developed out of the concept of urban sustainability, in particular based on, one of the more recent documents on urban sustainability which is that of the EU Expert Group on the Urban Environment (EEA-DG-JRC, 2002; European Commission, 1996). This states that sustainable urban development should encourage:

- control of the physical expansion of towns and cities
- a mixture of functions and social groups
- wise and resource saving management of the urban ecosystem
- better accessibility by different types of transport

- conservation and development of the natural and cultural heritage

Other frameworks for sustainable land use given in the European Sustainable Cities Project, the European Spatial Development Perspective, European Conference of Ministers Responsible for Regional Planning (CEMAT), and the Member State's Urban Exchange Initiative are listed in Expert Group on the Urban Environment (2001)

This section will first provide a review of policy measures currently in use to combat sprawl before examining the results of the simulations. The main areas of concern are environmental quality, consumption of land, mobility, adaptability of physical infrastructure, and segregation of social groups, while policies tackling these issues can be categorized by policy type: fiscal measures, land use planning instruments, housing and design in the private sector, transport, and other projects/actions in the public sector. These consequences of sprawl have been discussed in chapter three, and this section outlines the main policies to tackle these issues when seen as an outcome of urban sprawl.

Sprawl is seen as having negative impacts on the environment through the influence of urban form and transport on energy use and environmental emissions. The form of sprawl leads to increased automobile use and automobile emissions, higher energy requirements of space conditioning and lighting in low density single family homes, changes to air and water quality through use of lawnmowers, fertilizers and pesticides and higher levels of solid waste generation. Urban development is also perceived as converting farms, woodlots and open spaces to urban uses, affecting renewable resources, water quality, recreational activities and biodiversity (Anderson et al., 1976; Anderson et al., 1996; Banister and Watson, 1994; Clawson, 1971; Haines, 1986).

Increased use of the automobile is seen as an almost inevitable consequence of urban sprawl, resulting in negative impacts on the environment through its consumption of energy and auto emissions (Banister, 1995, 1996, 1997; Banister, 2001; Banister et al., 1990; Banister and Watson, 1994; Banister et al., 1997; Burns and Golob, 1976; Echenique, 2001; Gordon et al., 1989a; Newman and Kenworthy, 1988). In addition to changes in mode of transport, changes in urban form can result in reductions of these impacts. Firstly, increased energy conservation is possible by locating work and housing together, thus reducing journey trip lengths and enabling increased public transport use. Reductions in car emissions, mainly carbon monoxide and nitrogen oxides are enabled by preserving open space and dense vegetation within urban areas, which improves local air and water quality. Most of the environmental effects of urban sprawl can be addressed through policies targeting the other major issues of land consumption, mobility, adaptability of infrastructure, and social segregation.

The key issues of land consumption as listed by the European Commission (1996) are land loss due to population and employment decentralization, and the threat to local services by out-of-town retail. This is in part the result of traditional land use planning which has emphasized the segregation of functions – home, work, retail – leading to single use developments, with an increase in travel demand, energy consumption and emissions. While solving the problems of the industrial cities of the early century, this has lead to many problems associated with urban sprawl.

General guidelines for policies for urban land use have been given in Expert Group on the Urban Environment (2001). Among these are the recommendation for provision of market-based instruments to influence land markets, including voluntary agreements and tradable permits in urban land remediation and reuse, and the use of taxes to discourage green field development. The other point which is particularly pertinent to this section is the emphasis on regional polycentric development. The EU Committee on Spatial Development (1999) advocates inter urban polycentric development at the EU rather than city level, to promote complementarities between regions. This is in accordance with policies to tackle sprawl, as most of the negative effects of sprawl are regional in nature.

5.3.2 *Green Belt Policy*

The green belt policy is seen as one of the most effective policies used to contain urban sprawl. The green belt has a long history in the UK with policies implemented since 1935. The main intention of green belt policy is laid out in various government documents, for example Department of the Environment (1995). The main intention of the policy is to keep land permanently open in order to check the sprawl of built-up areas, prevent neighbouring towns from merging into each other, to safeguard the countryside from the encroachment of built development, to preserve the setting and character of historic towns, and to assist in urban regeneration. A major point of decision is whether the green belt is to accommodate future growth or to be used to avoid further population growth. This is not clearly stated in the UK case, but the implication is that the green belt should accommodate future growth as far as possible, such that *"they should be carefully drawn so as not to include land which it is unnecessary to keep permanently open. Otherwise there is a risk that encroachment on the green belt may have to be allowed in order to accommodate future development."* (Department of the Environment, 1995, section 2.8).

However, where this is not possible growth is to be channelled to existing urban areas with" *...(aim) of channelling development towards urban areas inside the inner green belt boundary, towards town and villages inset within the green belt, or towards locations beyond the outer green belt boundary."* (Department of the Environment, 1995, section 2.10).

A variation on the green belt policy is the urban growth boundary implemented in the U.S, which is a similar concept, but is drawn to accommodate growth for a specified period only (20-30 years) and is revised periodically , while the green belt in the UK is not approved for alteration except in exceptional circumstances. (Leo et al., 1998; Nelson and Moore, 1993; Pendall and Fulton, 2002; Weitz and Moore, 1998). A related tool used to control the pace of development in the US is the urban service area which is the area beyond which a cities infrastructure (sewer and water) does not extend. This is usually used to target growth into particular areas in a particular sequence, not to prevent development in the long term.

Preservation of the green belt requires a strong planning system. In the UK, the green-belt has been successfully retained with only 5-10 percent of the land allocated for green belt in the 1950's being developed (Munton, 1986). One important criteria for successful green belt policy is its implementation within a regional structure, otherwise there is the risk of shifting sprawl from one area to another with development leapfrogging the green belt, leading to dormitory suburbs which are dependent on the central city for employment. This is especially important where the green belt is tightly drawn and restricts the growth of the city. In the UK context, the policy is often implemented with the idea that satellite cities will be created outside the green belt (Pendall and Fulton, 2002).

The main side effect discussed is the impact of the green belt on house prices in the urban area. House prices are dependent on several factors: agricultural value, structure value, infrastructure value, present location value and future location value (Nelson et al., 2002; Phillips and Goodstein, 2000). The main impact of the urban growth boundary is on 'structure value', the opportunity cost of the resources used to construct the house. It is argued that green belts restrict the supply of developable land, raising its price and thus the price of housing.

Interviews carried out as part of the SCATTER project have investigated the impact of the UGB on Portland, Oregon (CASA et al., 2005). Oregon is one of the US states, which has the longest continuing history of statewide growth management and land preservation. It is a recognised leader of urban growth management in the US and many states are now implementing features of Oregon's planning system. Oregon uses urban growth management to:

- direct the regional demand for urban development into areas contained by urban growth boundaries (UBGs) and away from resource land;
- restrict ex-urban (beyond UGB) development so that it is compatible with resource activities;
- restrict resource land to resource activities.

Oregon's statewide goals are achieved through local comprehensive planning. State laws require each city and county to adopt a comprehensive plan which must be consistent with the state-wide planning goals.

The statewide planning goal n. 14 on urbanisation calls for each city to establish an *"urban growth boundary" to "identify and separate urbanisable land from rural land".* An urban growth boundary is essentially a line drawn around a metropolitan area that delineates where urban development may take place (inside the UGB) and where it may not (outside the UGB). Land outside UGBs is restricted to farming, forestry and other resource uses. The establishment and change of a UGB is a cooperative process between a city and the county or counties surrounding it. Urban Growth Management Agreements (UGMAs) are used to establish procedures for coordination between counties and cities that have jurisdiction within a specific urban growth boundary.

Although simple in concept, the construction of UGBs has proven difficult in practice. Part of the difficulty stems from the uncertainty concerning the rate of urban development which makes it difficult to determine exactly how much land to include inside a UGB. Too little urban land could cause land price inflation whereas too much would not prevent urban sprawl. However to enhance the possibility of successful growth management, the UGB in Portland has been accompanied by a detailed and comprehensive growth management programme which details land-uses, densities and public transport development.

Experts interviewed for this study viewed Portland as a classic example of best practice in that less land per capita had been consumed there than any other US city of comparable size, as a result of density targets which had led to average densities some 40 percent greater than the average US city. Moreover the downtown had not lost commercial and service functions, preventing the decline of the urban centre common in US cities. But the downside of all this was that housing in Portland was no longer affordable. It is now a city for the relatively well-off, all as a result of control of land supply. In fact the urban growth boundary that had been put in place to ensure these controls was slowly but significantly being extended to provide more breathing space for the city. If the wider region is considered, then the picture changes in that sprawl begins at a distance from Portland where the strict controls end and other municipalities and counties begin to exert their influence.

While the increase in house prices is evident, the causes are debatable, with evidence from other studies finding that while house prices have increased from 1991 – 1996, due to increased demand from employment growth in the region and a speculative market due to the initial surge in demand, rather than to restricted land supply. Outside this period of increased demand, house prices were not found to have risen significantly more than places without urban growth boundaries. (Downs, 2002; Nelson, 2002).

5.3.3 Other Regulatory Land Use Policies

Other techniques worth mentioning are zoning techniques, often used in weak planning systems with little ability to enforce stronger controls on development. These are used in areas where development is already allowed, and so should not be seen as a tool to prevent growth in greenfield areas. One major technique is cluster zoning which is targeted at suburban housing developments and attempts to group housing within a limited area and preserve the remainder for agricultural development. This process applies residential densities developed for the planning district, but will have higher densities and smaller lot sizes on individual sites. The main (often contradictory) views are that it can preserve agricultural land by providing land owners with an alternative to selling the entire farm, can provide a buffer between agriculture and residential development, and that it merely preserves the rural character of the area but does not provide for a working agricultural landscape (Daniels, 1997)

A major weakness of this tool is that it focuses on the individual site or development and does not take a strategic or regional approach, and so has limited success in preventing sprawl. It is unlikely to result in the preservation of agricultural land without larger scale regional planning. If used without a regional planning context, it may actually encourage sprawl by promoting residential development in agricultural areas. Where the technique is useful is in creating residential developments with larger areas of open space than traditional suburbs (Daniels, 1997). Even Arendt (1997), the main proponent of cluster development, admits that this technique is best suited for suburban fringe areas where urban growth is planned and not as a tool to conserve rural or agricultural areas.

Policies to preserve land consumption at the level of the individual housing development come in the form of New Urbanist designs, also known as traditional neighbourhood design and neotraditional design, and policies such as cluster development. These are primarily design solutions which provide a new style of suburban development and on their own cannot prevent sprawl. Indeed many of these developments are often on green field sites.

New Urbanist design is usually implemented in the North American context and is associated with the designs of Andres Duany and Elizabeth Plater Zyberk (Duany et al., 2000). The Duany/Zyberk design aims to construct new suburbs in the form of traditional small towns with a pedestrian scale and clearly defined centres. The ideal is to have commercial and service centres within walking distances, mixed uses, and high density housing with a mix of affordability, produced through condominiums and town houses as well as detached single family housing. Specific design elements include a short block grid plan, with short streets, houses close to the street, houses fronted by porches and on-street parking. These ideas have not been realized in recent projects, which have resulted in typical suburban development, which although slightly denser than average are too low density to support mixed use or public transport, and have been built on greenfields at the urban periphery (Al-Hindi, 2001; Banai, 1998; Bookout, 1992; Duany et al., 2000; Ford, 1999; Katz, 2000b; Talen, 2000). These developments have not provided affordable housing and tend to attract affluent home buyers. This is supported by reports on individual communities; for example according to McCann(1995), the Kentlands neotraditional development in Maryland in1995 had a gross density of 5.2 dwelling units per acre, not the planned 40 to 50 dwelling units per acre. The design principles appear to produce more pleasant suburban developments with a larger proportion of open space within the development, but have remained low density, single use suburbs.

5.3.4 *Fiscal Policies*

The main policy used to offset the cost of local government provision of infrastructure is the use of development impact fees (Barnebey et al., 1988; Huffman et al., 1988; Nelson, 1988; Nicholas and Nelson, 1988). New developments require local governments to extend infrastructure in the form of water, sewerage, drainage, and community services. Where urban sprawl has occurred, this has lead to expensive extension of services at great distances from existing development. This technique has been implemented in the US since the 1970's, requiring developers to pay for the proportion of new infrastructure generated by their developments. An impact fee program must be able to show that the development created by a new community creates a need for additional facilities, and that the new development will benefit from the facilities. The program is not appropriate as a means of financing existing deficiencies, and should not require payment of infrastructure and services beyond the level stated in existing planning standards. The actual process of calculating the proportion of development to be paid for by the developer is a complex one, and several formulas are given in (Nicholas and Nelson, 1988).

The main issue of concern is determining who pays the added cost of the impact fees, as this can be born by the landowner, the developer or passed on to the purchasers of new housing. Huffman et al. (1988) suggest that ultimately developers pass the impact fees on to the buyers, through either higher prices, or lower quality housing, but there has been little empirical work on this issue. However, this technique is more equitable for existing residents who are not required to pay for infrastructure and services which benefit new developments.

Other techniques used to preserve agricultural land and open space are fiscal measures, such as the purchase of development rights, transfer of development rights and land banking. Purchase of development rights (PDR) and transfer of development rights (TDR) work by applying a conservation easement to the land which is acquired by a land trust or planning agency. PDR involves direct purchase of development rights from landowners, and TDR involves the setting up of a preservation area and an area receiving increased development. In this case, landowners sell their development rights in the preservation area to developers in the receiving area. Land banking is essentially the fee simple purchase of land by a local government for use or resale at a later time. This method is more costly than the PDR and TDR programs.

These techniques have been used in the US context, and are often applied where planning control is weak. The technique is very successful in land preservation, but the main disadvantage of the PDR and land banking are the high purchase costs to the local authority. The TDR is less costly as these costs are borne by the land market. However there are high administrative and management costs. Information relating land conserved to costs indicates 205,000 acres preserved at cost of $400 million (Wright, 1993, 1994). An interesting study of land banking in Europe is provided by Enders (1986) who describes the setting up of a public real estate corporation, the EPBS, to help control development in the French Lower Seine River Valley. The regional plan required a land banking program with a cost of $4.5 -$6.5 million dollars. The jurisdiction of the EPBS covered the region under the plan, and was financed by a special tax named the 'special infrastructure tax', calculated as a percentage of the four direct taxes levied by local government. The tax rate is adjusted yearly depending on the amount of money needed by EPBS, but has a limit of 5 percent of the total of the direct taxes. The purchases of the EPBS are decided by the local government, and are resold only to local governments and the public sector. The program was seen as a success in enabling the purchase of land required to fulfil the Lower Seine River Valley Regional plan, and provides an example of how such schemes may be financed. The study again points to the need for these tools to be implemented within the context of a regional plan if successful land conservation is to occur.

5.3.5 Transport Policies

Key issues of urban mobility as listed by the European Commission (1996) are increased congestion of cities due to use of the private car, and the separation of home and economic activities, which creates difficulty in the use of walking, cycling and public transport. This has subsequent impacts on air pollution, energy consumption and rise in CO^2 emissions. There is a corresponding decrease in accessibility defined as the ability to reach necessary services, not by length of journey time. The main connection of transport to urban sprawl is its role in reinforcing inaccessibility and car dependence. This is partly due to the low densities of new development on green field sites which makes the provision of public transport difficult.

Various measures have been put forward to improve the accessibility of housing, jobs and services (Parsons Brinckerhoof Quade and Douglas Inc., 1996a, 1996b; Transit Cooperative Research Program, 1997). General guidelines for good practice have been set out by the Department of the Environment Transport and the Regions which recommends the following combinations of land use and transport policies which could help to reduce sprawl and its impacts. This document recommends locating housing and uses which generate high travel demand within existing towns and cities, followed by urban extensions and then around public transport corridors. The main aim is to improve accessibility to jobs, shops and services by non-car modes of transport, coordinate the location of urban growth with public transport improvements, and encourage greater intensity of development where public transport accessibility is good. Housing strategies which can be used to achieve this are outlined below (Department of the Environment Transport and the Regions, 2000).

A major policy to increase access to public transport modes has been the development of housing along transport corridors and transport hubs, particularly rail networks and stations, in order to increase compactness and housing densities in these areas. The aim of the policy is to increase the use of public transport and to increase the mix of workplaces, residential areas, services, shopping, leisure and cultural facilities in the area. Design objectives emphasize a range of housing types, apartments, townhouses and single family homes on small lots. This policy is often combined with reductions to parking standards to encourage public transport use and discourage car use.

In some cases, development is encouraged as a way to cover part of the costs of rail investment as rail systems raise land value, and on publicly owned land, this can be a substantial revenue generator. Some of the problems with transport-oriented developments (TOD) outlined in Belzer and Outler (2002) are that they often achieve high densities but fail to create mixed use developments. Transit-oriented developments have faced several difficulties, most importantly the difficulty of integrating the transport system, related transport routes and surrounding development. This development can serve as part of a broader regional strategy of decentralized concentration. However, the emphasis should be on function rather than form.

The impact of settlement pattern on car use has been looked at by Simmonds and Coombes (2000). This research examined a variety of scenarios in the Bristol area using a transport model developed by MVA consultancy for the Avon County Council. In the context of transport-oriented development, the most interesting scenarios are those termed A2, A3 and A4, which model respectively the concentration of employment in the part of the central area best served by public transport, concentrating housing closer to the centre along LRT lines, and concentrating employment and housing. Scenario A2 showed an increase in total volume of traffic and slight increase in commuting distance; A3 showed a 5 percent reduction in distance travelled by car and an increase in distance travelled by LRT; A4 shows an increase in commuting trip distance, and a decrease in shopping and other trip distances. There is a slight increase in traffic in the centre. The authors conclude that a more compact land use strategy will have little impact on total travel demand and total car use, unless mobility is restricted in general. This is primarily due to the weak influence of proximity on travel choices.

The rail network is extended or linked to other transport modes as a way of revitalizing city centres and sub centres. These policies focus on connecting the suburbs and sub centres to the city centre and to employment centres, such as business parks and industrial sites. However, this should be combined with land use policies such as transport oriented development which increases housing concentration in a main centre or in sub centres. The move away from auto dependency involves a combination of strategies focused around transport oriented urban form, parking, disincentives for car use and incentives for public transport.

Parking policies which are used as a disincentive to car travel and as a push to other modes of transport generally limit parking in the city centre. This should be balanced by ensuring that parking requirements are minimized but do not detract from development in the core or increase congestion, and that alternative modes of transport are available such as walking, cycling or public transport (Department of the Environment Transport and the Regions, 2000). This is also reflected by the US EPA(1999) who state that demand for parking should be determined not by generic standards but by building /development type and size, population and development density, availability of non car transport modes, and surrounding land use mix.

Specific policies with land use implications include :

- in-lieu parking fees – in this case a fee is paid to the local government as an alternative to providing on site parking. The fees go towards the provision of centralized off site parking by the local government.

- shared car parking spaces - parking is shared between uses with peak demand at different times of the day. This is most useful in mixed use areas or mixed use developments, where there would be a variety of uses with varying demands, such as office, retail and entertainment and where parking facilities would be in close proximity to each other.

- centralized parking - can be used to improve urban design and preserve the nature of historic communities. These sites are usually located at the periphery of the city, and the main concern is the proximity to facilities.

- maximum parking limits - these restrict the total number of parking spaces which can be provided, usually based on square footage of a specific land use. This is suitable where there are sufficient alternative modes of transport, and limits may be reduced with proximity to light rail stations. Associated problems are spill over of parking into residential neighbourhoods, and acceptability by developers, as such it is more suitable in areas with strong economies. An extension of this is the ABC policy mentioned by (LEDA, 1999) which sets maximum parking spaces for companies grouped into three categories: A locations with high quality public transport and limited car access are allocated the least spaces, B locations with good public transport and good car access are allowed more parking, and C areas with little public transport are allowed high levels of parking.

- parking freezes - the total number of parking spaces in an urban area may be set at a specified limit. This is viable where there are alternative modes of transport available and in areas with strong economies .
- demand reduction - attempts to reduce the demand for parking by subsidies for transport, paid by employers to cover the cost of employee's transport; cash out programs where employees are given cash, equivalent to the cost of parking, for not driving to work, transport improvements, pedestrian and bicycle amenities, and vehicle trip reduction programs, such as facilitating car pooling

The ABC policy, also described in section 4.4 sets maximum parking spaces for companies is based on A locations with high quality public transport and limited car access least spaces, B locations with good public transport and good car access more parking and C locations with little public transport most parking, spaces are set by local authority and could be more closely tied to land use and public transport to limit car use and preserve space used by car parking. Parking zones which put different restrictions on parking depending on local parking pressures, which provide different levels of parking for categories of consumers, commuters, residents, shoppers; transport levy on companies, integration of public transport and new development .

One of the main problems associated with urban sprawl is the dominance of modal share by the private car, with its associated negative impacts on the environment, and traffic flow. Policies to reduce the use of the private car can target push effects, pull effects or a combination of both. Push effects provide a more detrimental environment for the private car, such as for instance, parking restrictions, car bands, road pricing and speed management. Pull effects provide more incentive for use of alternative modes of transport, such as bus lanes, park and ride, cycle networks, and increased bus service.

Any decrease in the use of the automobile would need to be accompanied by sufficient levels of public transport. This potential for public transport provision is determined largely by the underlying land use structure, in terms of location of land uses, density and urban design. Parsons, Brinckerhoof, Quade, and Douglas Inc. (1996) have found that the urban forms most supportive of public transport are employment in a single main centre, compact regions with a limited number of sub-regional centres, and sub-regional centres in rail transport corridors.

The other major factor influencing public transport is density, the main factors being overall housing and employment density. Findings on residential density thresholds for use of public transport to travel to work are that below 20 persons / ha driving increases and below 30/ ha bus service decreases (Newman and Kenworthy, 1989). According to Parsons, Brinckerhoof, Quade, and Douglas Inc. (1996) as residential densities increase in the transport corridors, vehicle kilometres travelled decreases. The effects of density are interrelated with employment centre size, corridor level urban structure, transport service characteristics, and supply and price of parking. Namely, as the CBD size increases, light rail use increases with higher employment densities at stations along the route increases transport use. Stations with parking and feeder buses have higher use, and similar results occur where parking is more accessible around stations.

The other main influence is land use mix, that is the number and type of land uses and the design of the neighbourhood. Mixed land uses are seen to encourage lower vehicle trip use and higher non-motorized use such as cycling and walking, a more even spread of trips through out the day and week, and to provide opportunities for resource sharing, such as parking.An important point is made by Parsons, Brinckerhoof, Quade, and Douglas Inc. (1996) that the most effective transport policies to combat sprawl are integrated with land use decisions.

This reinforces the findings mentioned above, that effective public transport use is influenced by urban form and density, and it introduces the idea that public transport in turn influences the revitalisation of the inner city. The main measures are use of adequate density, mixed uses and polycentric plans; placing settlements along public transport oriented sub centres; adapting the public transport network to the urban structure to improve accessibility; the reactivation and redesign of stations to fit the urban context and improving linkages to other transport modes; and providing a mix of uses around stations

The following policies have been suggested by Leda (1999) as a means of improving public transport use and decreasing the use of the private car:

- high automobile taxes - taxes on the purchase of a new vehicle and car registration taxes when can decrease car use when set at a high enough level

- high taxes on fuel - can decrease discretionary driving and there is some evidence that longer term responses may alter location decisions in housing location and use of alternative modes of travel.

- versement transport - this provides a way to pay for public transport through a tax which is a percentage of the salaries on companies with over nine employees.

- getting the business in the right place - this policy ties public transport routes to offices and new neighbourhoods. It provides an alternative to car transport and also allows for reduced provision of car parking as offices are accessible by public transport.

5.3.6 *Other Fiscal Policies*

One of the effects of urban sprawl coupled with the contextual changes in income and lifestyles, are changes in the type of housing and residential location. The result in most cases is that middle income families move out to the suburbs and poorer families and immigrants are concentrated in the inner cities, which leads to problems of economic disadvantage, unemployment and social stigmatisation. In general, policies which aim to address these spatial divisions promote links to public transport through housing located along major nodes which have good access to public transport. Other factors are: developments which contain a mix of land uses either on site or within individual buildings, provision of greener residential environments to increase the quality of the residential environment, improving the permeability of land for storm drainage and biodiversity, and improving the energy efficiency of housing. In addition, urban design should fit the wider context of the town, promote safety, public health, crime prevention and community safety, encourage efficient use of land , for example 30-50 dwelling units/hectare, with more intense development at public transport nodes, and increase flexibility in parking standards (Department of the Environment (2000).

These ideas are common components of schemes for urban revitalization, which are used to address the spatial imbalance between the core and the suburbs. In order to assess the usefulness of such schemes, it is necessary to examine the history of intervention in the city centre. The first such measures are found in the urban renewal policies of the 1930's to the end of the second world war. These policies focused on slum clearance, removing low rise private market housing of poor quality and replacing it with flats in big blocks of public housing. Criticism was made of the cost of forced relocation for residents, the destruction of communities and of the housing design of multi story blocks which were not suitable for family life or low income families. The second stage involved neighbourhood rehabilitation in the 1960-1970s; these programs focused on comprehensive rehabilitation programs rather than just housing, attempting to improve existing housing and increase the level of services, rather than demolishing and rebuilding. In the 1980s, the focus turned to economic revitalization. The two most well known examples are through gentrification and public private partnerships.

These often created economic improvements but did not lead to benefits for the existing residents. Important lessons from these policies are that successful revitalization should not promote residential segregation of lower income groups, that a single solution is not suitable for all areas, and should simultaneously provide for economic development and social equity, using a gradual approach which preserves existing structures (Carmon, 1999).

Before addressing specific policies for core area revitalization, it is important to look at the demand for suburban housing, as housing location is one of the key determinants of successful revitalization. The main demand has been for low density suburban housing; however, there are several types of consumers preferring denser neighbourhoods. One of the major indicators of preference for housing is age group. According to Myers and Gearin's (2001) survey of US households, young parents are attracted by high quality schools in suburban neighbourhoods, older adults are attracted by urban amenities, young adults prefer access to shopping, and late to middle aged adults focus on public transport and access to shopping. The preferences for households are somewhat contradictory. Households with children favour pedestrian design but also easy auto use; households without children prefer smaller yards but require quiet and privacy, and households aged 50 or under prefer open space and pedestrian use but also larger lots and lower density, while those over 50 prefer smaller lots, easy auto access to commercial areas but are also more in favour of public transport and access to services. There is a demand for the amenities of suburban housing, but at the same time a desire for the potential urban amenities of pedestrian use, smaller lots, access to public transport and services. It appears that demand for suburban growth is likely to continue but that there is a target market for core area housing in the childless households, particularly older adults and young singles.

Lang et al. (1997) explore a way to identify these groups using geo-demographic marketing. This technique uses lifestyle typologies based on demographic data and geographic data to segment the population into groups. Target marketing can identify potential urban dwellers by focusing on consumer tastes in housing in particular areas. However, it does not explain why people move. One policy which attempts to change the demand for housing location is the 'location efficient mortgage' (LEM) piloted in the US cities of Chicago, Los Angeles, San Francisco and Seattle. As described by Blackman and Krupnick (2001), this provides a higher mortgage for families choosing 'location efficient' areas, where employment and services are within walking distance or accessible by public transport. The LEM is insured by the federal housing administration in the event of default, and in theory, default rates are offset by the decrease in automobile related expenditure, due to the transport efficient location. The LEM provides a 15-30 year fixed interest mortgages of up to $240,000 (US) on a one unit house.

There has been little study of LEM's, but the two main issues are whether they will help to prevent sprawl and whether they will create an increase in the default rate. It is the latter which has been the subject of discussion thus far. However, econometric modelling by Blackman and Krupnick (2001) shows that there is a higher probability of default as the transport cost savings do not offset the propensity to default.

Policies focusing on the supply side aim to revitalize urban areas by improving the attractiveness of inner core areas primarily through mixed use development, with related policies of urban design, infill housing and traffic calming. The main aim is to encourage investment or reinvestment and relocation of housing in the city centre, andmixed use is seen as one way to do this. The Transportation Research Board - National Research Council (2002) also highlight the importance of personal security and quality of public schools as factors in attracting households and firms to move to the core area.

Mixed use involves increasing the intensity of land uses, for example mixing housing forms and tenures, which increases housing density. It also involves increasing the diversity of uses by mixing compatible uses, for example, high density residential in commercial and office districts, and integrating segregated uses, for instance, industry and other urban uses. This last feature is at the most extreme end of the concept, and may not always be suitable. In a study of Canadian cities, Grant (2002) examines the success of mixed use. She examines the success of mixed uses in Toronto which is largely due to the focus on infill projects on old industrial sites such as the St Lawrence neighbourhood, gentrification, and planned mixed use along transit lines. The policy appears most successful in large cities, where mixed use is supported by market demand, as similar initiatives in smaller Canadian cities have met with little success. Mixed use has also faced opposition in the suburbs due to unreceptive markets, and areas allocated for mixed use in development plans have remained segregated with little change in affordability or increased economic vitality.

In addition to mixed use, one way of making the city core more attractive is through traffic calming. This is often part of measures to provide 'transit friendly streets', which establish a priority for public transport, reduce vehicle speeds, provide more accessibility for pedestrians, and improve the liveability of communities. Traffic calming measures include traffic management strategies, and physical design measures. These include centre city passes, truck restrictions, signal systems, parking management, road undulations, humps, rumble strips, speed tables, interrupted sight lines through S bends, and staggered parking. Traffic calming according to Transit Cooperative Research Program (1997) has resulted in more efficient buses with better access as there is less competition over street space, and pedestrians have easier access to transit stops.

Methods for financing urban revitalization have typically been through direct public expenditure and use of subsidies. This section will examine fiscal methods of financing revitalization, based on the use of tax based incentives to back up planning and regulation, and public sector intervention through the market. These measures attempt to offset the disincentives for private market investment due to poor perceptions of property market performance, slow rental growth, and volatile land markets. The policies discussed in McGreal et al. (2002) include:

- Tax Incremental Financing (TIF) - which finances urban redevelopment through future increases in property revenue. It uses existing property tax revenue but reallocates the way it is used. The project areas which are eligible for the funding are set by law and the amount of tax revenue generated by the area is set as a baseline. The property tax base is then frozen in the district usually for 20 years. Tax revenue collected over subsequent years is used to pay for redevelopment projects. Once redevelopment is completed, the tax district is removed and the local government is expected to regain its expenditures through the increases in property tax value due to the improvements made.

- Capital Allowances - allow reductions in corporation and income tax for up to a ten year period. As instituted in Dublin, these allow owner occupiers to offset all allowances in the first year. They also provide a reduced corporation tax of 10 percent in specific industries, implemented within enterprise zones. They double rent allowances on commercial leases available to the tenant or a commercial lessee in an urban renewal area, and provide rate remissions relief for 10 years payable in relation to enlargement or improvement of existing commercial buildings.

- Incentive Property Taxation - is a two rate property tax with higher taxes on the assessed land value of a parcel than on the building. The tax has the potential to influence land development if it is heavier than the speculative gain from holding the land against inflation. The advantage of this measure is that it provides an incentive to develop vacant infill sites by reducing the amount of tax to be levied on improvements, thus increasing the revitalization of buildings in the city centre, and discouraging land speculation by holding unimproved land (Gihring, 1999)

One of the main issues of urban revitalization is the role it plays in residential segregation through the process of gentrification. In a nutshell, as areas are improved, land and housing prices rise, pushing out low income renters. However, continuous upgrade of the housing stock is necessary and one strategy used is to gentrify areas which can be supported by the market but allow deterioration of nearby neighbourhoods which displaced households can move to. This has been seen as a short term solution with a more appropriate long term approach being to raise the purchasing power of low income household through housing assistance.

The physical effects discussed in the section on adaptability also result in concentrations of low income residents. The main solutions have been to remove this concentration by creating mixed income groups either through economic subsidies to supplement the market cost of renting or by direct provision of below market cost housing. The other lesser strategy is to encourage higher income groups to move to low income neighbourhoods. This generally occurs through the process of gentrification.

The main strategy to reduce segregation has been to increase the economic capacity of low income households to meet housing costs and to overcome the resistance of higher income groups to the movement of lower income households to their neighbourhoods. More recent trends have been to provide affordable housing through the market using market housing to subsidize affordable housing on the same site. This follows a rolling back of public sector investment in social housing, and a decrease in the public housing stock through right to buy sales (Malpass and Mullins, 2002). Methods of reducing segregation are discussed below.

One method is to include policies about affordable housing in local and urban development plans. These should set required levels of new affordable housing, outline measures to achieve this, and identify suitable areas for affordable housing. The strategy set out by the UK government (Department of the Environment, 1996), Great Britain Department of the Environment (2000), Department for Transport Local Government and the Regions (2002) is to promote a mix of affordable housing types such as family housing and homes for smaller households to avoid concentration of low income groups and to use low cost market housing as well as subsidised housing.

Housing Vouchers are a direct housing subsidy paid to the tenant. The household pays 25- 35 percent of the rent on the unit, and the government subsidy pays the difference. This form is most favoured by housing experts due to the lower cost of tenant based programs (McClure, 1998). The suitability of tenant based programs depends on the supply of available units meeting minimum standards in the housing market, the level of participation from the target population, and the social needs of that population. This policy has the advantage of being cheaper than project-based programs, and can be used to reduce segregation in core areas by enabling low income households to move out.

Land consumption generated by uncontrolled and unplanned growth and location of (mainly residential) urban functions is an issue of great concern for local and regional governments preoccupied by the possible reduction of natural resources and of their environmental quality and by the increased costs of public infrastructure provision. Two are the most common approaches presented by the case studies: control of land consumption by a reduction of the supply of land available for development and one based on promoting or imposing urban growth only in selected locations and with selected land-use structure and density levels.

5.4 The Simulation of Policies to Combat Sprawl

The policies assessed in the simulation are listed in Table 5.4. The simulations were carried out on three case cities of Brussels, Helsinki, and Stuttgart. These cities were chosen from the six case cities for the simulations because new regional-level public transport infrastructures or services will be implemented in Brussels and Helsinki, and were implemented in Stuttgart prior to the SCATTER project. In Brussels this took the form of a planned Regional Express Railway Network (REN), in Helsinki a plan to distinguish between road and public transport elements and to develop public transport links with more orbital connections, and in Stuttgart the extension of a light-rail line parallel to the motorway (built in 1992) and the completion of a link to the motorway in 1978. The aim of the simulations is to assess the extent to which these infrastructure projects could trigger urban sprawl, by providing faster or cheaper access to the city centre from the suburbs. The simulations also assess the extent to which the policy measures reduce any negative impacts in terms of the expected relocation of activities and population.

Land use and transport policies were evaluated for all three case cities. These included a combination of fiscal and regulatory measures. This allowed for comparison of the effectiveness of fiscal measures compared to more traditional regulatory policies, and also the effectiveness of fiscal measures when applied to land use in comparison to transport. The land use policies were a development impact fee on suburban residential developments, combined with a reduction in the tax in the urban areas, a regulatory measure on office location (ABC policy), and a fiscal measure applied to offices. Transport pricing policies of road pricing which increases the car use cost per km, cordon pricing and a reduction in the public transport fare.

The land-use/transport models are used as they evaluate the effectiveness of policies against urban sprawl, through the simulation of the interactions between transport and land use. They make it possible to assess long term impacts of transport and land use policies on the spatial structure of activities and population and on patterns of mobility. The policies assessed in the simulations were selected from the policies reviewed in section 5.3.1. Those selected were deemed to be most successful in combating sprawl. The policies were also selected to include a combination of traditional regulatory land use policies, transport policies and also fiscal policies which are less widely implemented in the European context.

Table 5.4: Policies used in the simulation of sprawl

Policy code	Description of the policy		
	Brussels	**Stuttgart**	**Helsinki**
31	**Fiscal measures applied to residential developments**		
311 – *Common policy*	**311B** : • annual tax (development impact fee) applied on households locating in non-urban zones and who moved to those zones between 2001 and 2021 with REN (=scenario 111B) ; the tax amounts to 670€/housing/year (which corresponds to a one-shot tax of 13400€/housing distributed on 20 years) • fiscal incentive (tax reduction) applied to all households located in urban zones (60 communes) : it is calculated to redistribute the impact fee, which leads to 37€/housing/year for all households	**311S** : • annual tax (development impact fee) applied on households locating in non-urban zones (about 670€ / household / year) and redistribution of the revenue of impact fee to the urban areas, as fiscal incentive to all households located in urban zones (Stuttgart, Ludwigsburg, Sindelfingen, Böblingen, Esslingen and Göppingen)	**311H:** annual tax (development impact fee) : Same as in Brussels. Level fixed to 670€/year/housing.
313 – *Local policy*	**313B:** Same measure as 312B but the fiscal incentive is applied to a total of 12 zones including central zones of Brussels and central zones of the main secondary cities of the study area.		**313H:** Same as in 311H but level fixed to 1000€/year/housing

Table 5.4 (continued)

32	**Regulatory measures applied to offices, inspired form the ABC theory**		
321 – *Common policy*	**321B** : ABC-type policy applied to a part of the tertiary sector: • obligation (regulatory measure) for all jobs of the employment sector "business services", to locate in A-type zone • an A zone is a zone served by high quality public transport at regional scale; in Brussels, they are defined as zones served by an Inter-City-Inter-Region railway station; in this scenario, there are 14 A-zones in the Brussels-Capital Region + in the periphery.	**321S** : ABC-type policy applied to a part of the tertiary sector: • obligation (regulatory measure) for all jobs of the employment sector "business services", to locate in A-type zone • an A zone is a zone of the capital of a district (NUTS3). In general those zones are also served by high quality public transport at regional scale. In these scenario, there are 7 A-zones in the Stuttgart Region	**321H:** ABC-type policy applied to a part of the tertiary sector.
33	**Fiscal measures applied to offices, inspired form the ABC theory**		
331 – *Common policy*	**331B**: ABC-type policy applied to a part of the tertiary sector: • tax on jobs of the employment sector "business services" locating in non-A-type zone; the tax amounts to 1983€/job • an A zone is a zone served by high quality public transport at regional scale; in Brussels, they are defined as zones served by an Inter-City-Inter-Region railway station; in these scenario, there are 19 A-zones in the Brussels-Capital Region + in the periphery.	**331S:** ABC-type policy applied to a part of the tertiary sector: • tax on new jobs of the employment sector "business services" locating in non-A-type zone; the tax amounts to 976 €/job • an A zone is a zone of the capital of a district (NUTS3). In general those zones are also served by high quality public transport at regional scale. In these scenario, there are 7 A-zones in the Stuttgart Region	**331H** : ABC-type policy applied to a part of the tertiary sector. Same as in Brussels. Level fixed to the yearly season ticket for public transport ticket (a cross metropolitan ticket for all, 710.8€), as in Brussels. Implemented as percentage decrease.

Table 5.4 (continued)

4	**Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car**		
41	**Increase of car use cost**		
411 – *Common policy*	**411B**: increase by 50 % of the cost per km for all drivers.	**411S**: increase by 50 % of the cost per km for all drivers	**411H:** car operating costs +50% (increase by 50 % of the cost per km for all drivers)
412 – *Common policy*	**412B**: cordon pricing (the cordon is located just inside the Ring road which surrounds the Brussels-Capital Region and some adjacent communes) ; tariff : 7.5 €/day applied to all drivers	**412S:** cordon pricing (the cordon is located just inside the city of Stuttgart and the adjacent communes Ludwigsburg, Sindelfingen, Böblingen and Esslingen); tariff: 2,1 €/day applied to all drivers	**412H:** Cordon (peak) pricing, corresponding to 60 of minutes time value (2,5€) in orbital cordons or 30 minutes of time value (1,3€) in radial cordons
423 – *Local policy*	**423B**: Strong capacity restriction + increase in the parking tariff, both in the inner city and in the urban centres of the periphery. The study area is divided in 2 area types : ▪ type 1: inner city (8 communes) + urban centres of the periphery (15 communes): - parking capacity restriction: 1 place for 8 jobs - parking tariff: long term (home-work trips): 12.5 €/day; short term: 6.25 €/day ▪ type 2 : rest of the study area: - parking capacity restriction: 1 place for 2 jobs - parking tariff: long term (home-work trips): 6.25 €/day; short term: charge free		

Table 5.4 (continued)

5	**Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by providing PandR facilities**		
51	**Change in the fare of public transport**		
512 - *Common policy*	**512B**: decrease of fare by 20%, applied to all public transport users	**512S**: decrease of fare by 20%, applied to all public transport users	**512H:** decrease public transport price by 20 %
8	**Combinations of selected measures**		
813 - *Common policy*	**Combination** 813B = **411 + 511 + 311 + 331:** ▪ increase by 50% of the private car cost/km applied to all drivers ▪ decrease of PT fare by 20% for home-work trips ▪ fiscal measure on residential developments: see scenario 311 ▪ ABC-type policy applied to a part of the tertiary sector: see scenario 331	**813S** = 411 + 512 + 311 + 331	Combination **813 H** = 411 + 512 + 311 + 331

The indicators used to evaluate the simulations are chosen to assess whether the scenario generates sprawl or concentration, and to assess the impacts of the scenario on the environment, quality of life and the economy. The land use indicators are calculated both for the core metropolitan area and for all the urbanised zones together (i.e. including secondary urban centres). The indicators, described in Table 5.5 measure changes in land use through shifts in households and jobs from the urban centre to other urban zones, and through the H^{rel} measure of concentration. Changes in transport patterns are assessed through measures of mobility, modal share of public transport and total car mileage. A major cost of sprawl particularly in relation to infrastructure projects is the impact on the environment, which is measured by changes to CO^2 emissions

Table 5.5: Indicators used to assess the simulations

City sprawl indicators	Unit
Land use	
Households in urban centre	#
Households in urban zones	#
Jobs in urban centre	#
Jobs in urban zones	#
H^{rel} measure of concentration	km^2
Mobility pattern	
Average home-work travel distance	km
Average travel time (all modes)	minutes
Public transport	
Modal share of public transport	%
Road traffic	
Total car mileage	vehicle-km per year
Environment	
CO^2 emissions	/1000 inh

The urban centre described in the indicators matches that discussed in chapter four. However, the urban zones have a slightly different definition. The urban zones included for Brussels are the Brussels city centre (capital region), Flemish urban communities (yellow) and other urban zones (grey), as shown in Figure 5.4.

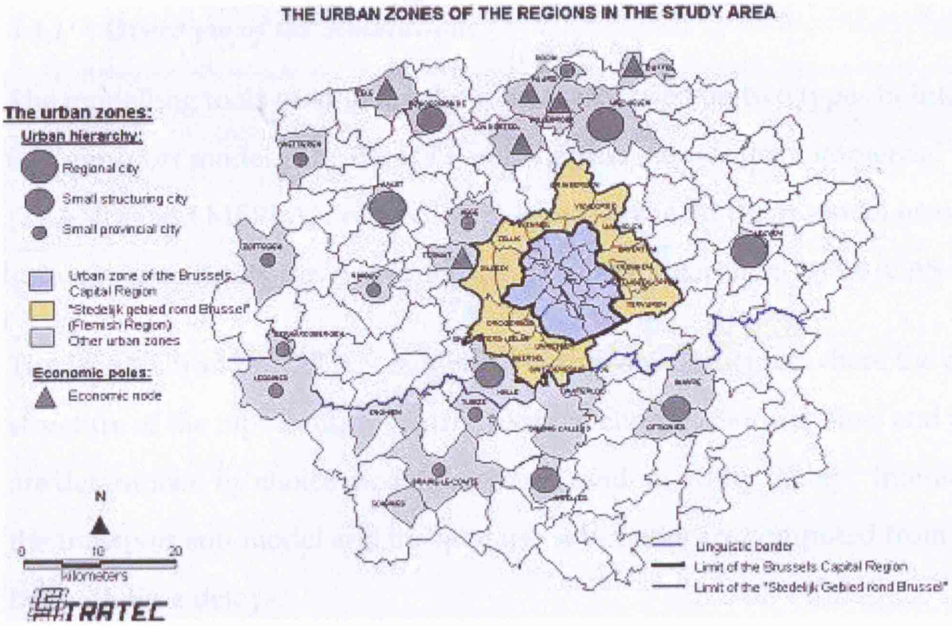


Figure 5.14: Urban zones of Brussels for the simulations

For Helsinki, the area covered by the urban zones is described in Figure 5.15 as the city centre (inner Helsinki Metropolitan Area (HMA)), outer HMA, HMA suburbsn and other conurbations outside the HMA.

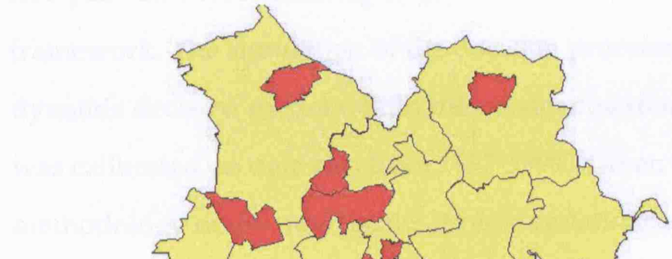


Figure 5.15: Helsinki centre (red), Inner Helsinki Metropolitan Area (HMA) (dark blue), outer HMA (mid-blue), HMA suburbs (light-blue), rural municipalities (yellow).

In Stuttgart, the urban centre and urban zones are those described in chapter four as the urban centre and outer urban ring.

5.4.1 *Overview of the Simulations*

The modelling tools used in the three cities are based on two types of integrated land-use/transport model. The Brussels and Helsinki models use commercial software (TRANUS and MEPLAN respectively), whereas the Stuttgart model uses a specific software specifically developed for the case of Stuttgart by STASA (CASA et al., 2005).

The TRANUS and MEPLAN models have the same structure where the coefficient structure of the input-output matrix, location choices, mode choices and path choices are determined by choice models based on random utility theory. Interactions between the transport sub-model and the land use sub-model are computed from these choices but with time delays.

Each model starts from a different base scenario. In Brussels, the model was calibrated against the data observed in 2001. The reference scenario at horizon 2021 was built-up outside the model and the policy measures were simulated starting from that 2021 reference situation. The Helsinki's model starts from the base year 2001, and runs in a five-year time thresholds up to 2021. The STASA model is based on a master equation framework. The simulation of the decision processes is based on a stochastic and dynamic decision model within the master equation approach. The Stuttgart model was calibrated on data sets from 1997-1999. Given the different base scenarios and methodology of the models, the three simulations are compared using only the absolute or relative variations in the indicators caused by the measures. The absolute value of the indicators themselves are not used and thus the predictions are evaluated relative to the baselines and to each other.

The Brussels land-use model is based on the TRANUS land use / transport model developed by MODELISTICA of Caracas, Venezuela, a spatial input-output model. The economic production sectors include private local services, retail trade and business services (not allowed to locate on industrial land) and are configured as endogenous sectors while agriculture, industry, heavy tertiary, Belgian public administration, international public administration (EC, NATO), public local services, business services (allowed to locate on industrial land), and teaching (primary, secondary and high education), are set as exogenous sectors.

Household categories (classified according to the characteristics of the household's head) consist of white collar (families or one person households), blue collar (families or one person households), non-active people, people over 65 and students living on campus. For some of these, further distinctions are made according to the number of persons in the household. Land categories consist of 3 types: low and high density residential land, and mixed economic activities land use. The interrelations between the different factors are characterised by the coefficients of an input - output matrix that were derived from the national census and national surveys on labour force and on household expenses. These coefficients are elastic for land consumed by economic sectors and households .

Transport supply is represented by a single integrated multimodal network whose details are adjusted to the scale of the zones under consideration. The modelled transport network consists of the primary road network (ca. 1300 links), the railway network serving the study area (ca. 500 links), the metro and pre-metro (i.e. tramway in tunnels) networks (ca. 100 links) representing 85 different link types. Buses are not modelled explicitly: they are represented by links gathering zone centroïds to railways or metro stations. However, separate bus links have been designed for the express buses running mainly in segregated lanes, modelled over several scenarios.

The Brussels model considers passenger transport only. The multi-path search is based on a multimodal shortest path search procedure (i.e. a path between a given O-D pair may include several modes), and the assignment of demand on the paths is based on a conventional multinomial logit procedure based on the *generalised path cost*, considering travel time and cost. Available modes in the reference scenario are car (with a distinction between single-occupancy car and high-occupancy car), metro and pre-metro (i.e. tramways in tunnels), train, Regional Express Railway Network in Brussels (REN) and express buses.

The demand for travel is represented by a set of O-D matrices of flow volumes in the morning peak hour (7h00 - 9h00): high/medium income home-to-work trips, low income home-to-work trips, non-regular trips (i.e. other than home-to-work or home-to-school), as endogenous matrices, and home-to-school trips, commuting from outside the study area and transit trips as exogenous matrices.

The Helsinki simulations are based on existing MEPLAN model application of the region. MEPLAN is a comprehensive land-use and transport interaction modelling package that can represent strategic multi-modal networks/services and estimate transport demand based on the spatial economic interactions between the households, employment and land use (see *e.g.* Echenique, 1994; Williams, 1994; Harris, 1996). The modelling process follows closely the TRANUS process above. The urban model applications of the MEPLAN framework follow a traditional four-step transport model supplemented with a land-use location model. For the various overall phases (from demand to supply), the model predictions for a given period are as follows:

- the location of the households and firms (employment);
- the generation of trips from the interactions between households and employment;
- the distribution of the trips between zones in the area;
- the mode split of the trips into car, public transport and slow modes trips;
- the assignment of the vehicles on the transport networks.

The process modelling the economic interactions and socio-economic characteristics of the locations of the households and firms in the region is based on a spatial input-output framework for endogenous employment and population that has elastic consumption functions. The chain of production and consumption is started based on the exports and other exogenous employment and inactive (non-working) households. Various constraints (e.g. rents based on available floorspace) increasing the costs of location affect this process in addition to the accessibilities due to transport system demand and supply characteristics.

In the STASA model, the econometric models utilised are of the stochastic discrete choice type within a nested logit formulation. The hierarchical structure is adopted extensively in the transport model from trip distribution to modal split and the generation of trip matrices. This gives a strong theoretical foundation to the utility maximising and also leads to a consistent evaluation based on consumer surplus calculations inherent in economic welfare theory. The commuter flows are modelled via the master equation framework. In order to analyse both inter- and intra-regional flows the STASA-transport/land-use model had to be modified. In the following, a rather short description of the general modelling framework is presented focussing on the differences with other "integrated approaches" which should become obvious.

Investments in the transport sector and communication networks improve the accessibility and attractiveness of suburban areas. This may lead to a redistribution of migration flows and traffic flows and is discussed as one possible reason for urban sprawl. The quantitative treatment of those nested processes of the different subsystems (transport-, population-, communication-subsystem) and its interactions require integrated modelling. On the one hand, the dynamics on the macrolevel - i.e. the development of the traffic subsystem and of the urban/regional subsystem - is determined by the behaviour of the individuals on the micro-level. On the other hand, "attractivity" differences between the spatial units (traffic cells) which depend on the macro-variables, influence the decisions of the individuals as well. Apart from rational motives of the actors several elements of uncertainty, e.g. irrational behaviour as a result of insufficient information, have to be taken into account. Hence, the description of decision processes is based on a stochastical and dynamical decision model within the master equation approach.

The traffic subsystem as well as the urban/regional subsystem form a complex intertwined system. Its dynamics take place on different time scales but are modelled making use of the same principles:

- The daily flows of traffic in the region of Stuttgart are the result of very quick decision processes of actors realizing a trip between two traffic cells (origin - destination) for a special purpose. Decision processes for a certain destination, the moment of the setting out, the mode of transportation, the choice of the route etc. take place on a very short time scale.

- The development of the urban/regional subsystem (e.g. spatial population distribution) is a process on a long-term time scale. The population distribution changes because of migration by individuals. The equations of motion which describe the migratory behaviour contain transition rates, i.e. migration flows between the cells. These flows depend on accessibility measures (coupling to the transport subsystem) and "attractivity" differences as a result of different regional advantages.

5.4.2 *Interpretation of the Simulations of Urban Policy*

The three models noted above were each used in simulating different policies which impacted on sprawl. Table 5.6 compares the policies against each other, and shows the relative variation for each indicator averaged for the three simulations. The average change in each indicator serves as useful comparison when viewing the results of the simulations for the individual cities as some policies resulted in large changes for one simulation with very little change in the other two simulations. When evaluating the effectiveness of a policy it is therefore useful to also examine the average change for all three cities.

Table 5.6: Average levels of relative variation for the simulations

	impact fee on suburban residential developments 311	fiscal measure 313	regulatory measure on offices (obligation to locate in A-type zones) 321	fiscal measure on offices (incitating to locate in A-type zones) 331	increase of car use cost by 50 % 411	cordon pricing 412	decrease of public transport fare by 20 % 512	combination 411+311+331+512 (511 for Brussels) 813
Number of households in urban zones	0.5	1.5	0.7	0.3	0.6	0.7	-0.5	1.0
Number of households in the urban centre	1.0	4.2	1.8	0.6	1.7	2.5	-1.4	1.9
Number of jobs in urban zones	0.2	0.3	1.4	0.3	0.1	-0.3	0.1	0.6
Number of jobs in the urban centre	0.3	0.8	4.9	0.8	0.7	-1.8	0.2	1.6
Car mileage	-0.3	-0.5	-0.6	1.7	-10.9	-14.5	-1.1	-10.5
Share of public transport	-0.1	-0.1	3.6	0.2	5.2	4.2	6.4	16.3
Average travel time (all modes, all purposes)	-0.1	-0.9	0.0	0.1	-2.5	-1.6	2.4	-0.2
Average home-work travel distance, all modes	0.1	-1.8	-0.3	0.0	-8.6	-2.5	9.7	-0.2
Passenger-kilometers by public transport	-0.1	-0.7	1.2	0.2	2.7	1.8	8.4	11.3
CO2 emissions from transport	-0.3	-0.5	-0.6	0.1	-9.3	-11.4	-1.5	-9.3

There is no one dominant policy which was most successful in improving the concentration of growth in the urban centre and urban zones, with the impact of the policies also differing for the urban centre and the urban zones. For the urban centre, the most successful policy on average for increasing the concentration of population is the ABC policy (policy 321), as shown in Figure 5.16. This is also the most successful for increasing job concentration. For both population and employment, this policy has the highest impact in reducing urban sprawl.

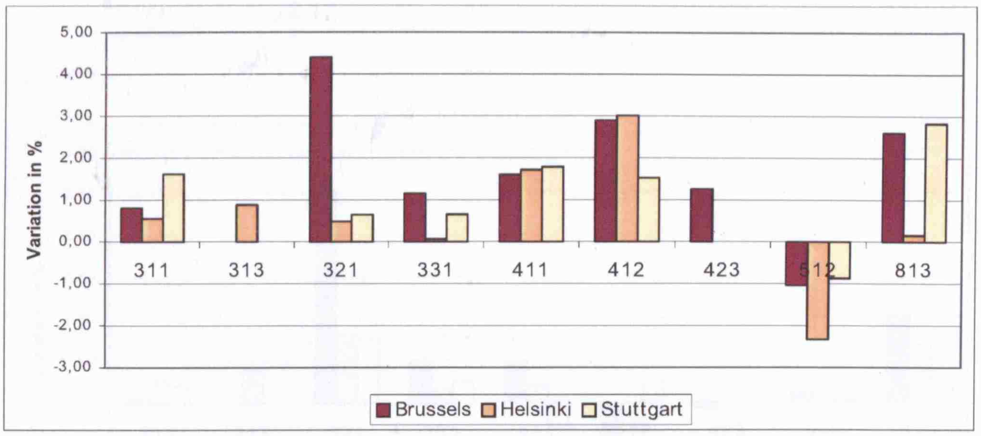
Looking at the detailed graphs in Figure 5.16, the success of this policy is skewed by the much higher increase in population and employment in Brussels, while the level of increase of population and employment as a result of this policy for Stuttgart and Helsinki is lower than for other policies. The second most successful policy for the urban centre for increasing population concentration are transport policies , as also illustrated in Figure 5.16– in the urban centre cordon pricing (policy 412 in the figure) shows the strongest relative increase in population, while for jobs, the fiscal measure (policy 331 in the figure) shows the most impact.

Among the case cities there is a wide variation in the effectiveness of the policies in attracting population and employment to the urban centre and urban zones. In Brussels, the regulatory land use ABC policy is most successful for increasing both jobs and population for the urban centre and urban zones. In Stuttgart, the transport polices of increased car use cost and cordon pricing are most successful in increasing concentration of population, while the regulatory land use policy of ABC is most successful in increasing job concentration. In Helsinki, the transport policy of cordon pricing has the most impact in attracting households to the urban centre, while the increased car use costs shows the most increase in households in the urban zones. In terms of job concentration the ABC policy is most successful in the urban centre in Helsinki, and also in the urban zones.

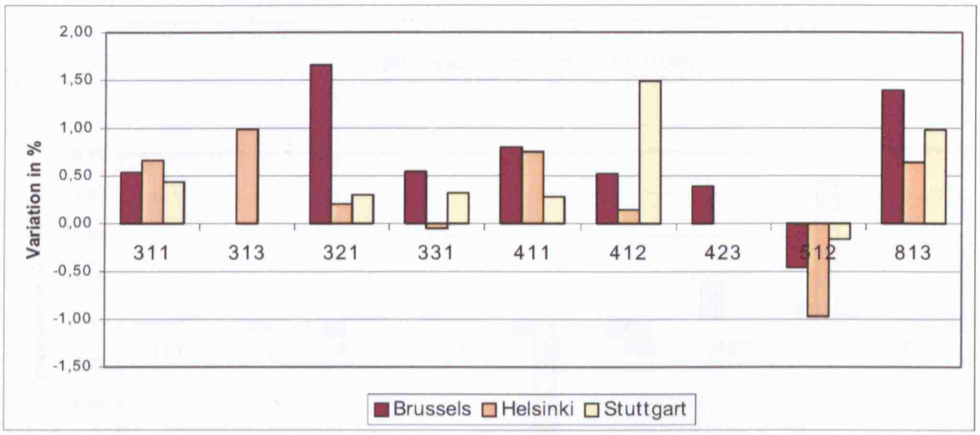
Interestingly, the cordon pricing has a negative impact for all three case cities on the number of jobs in the urban centre. The decrease in public transport fare has a negative impact on population movements, increasing the movement outward and has only a small positive increase in job concentration. The fiscal measures have very little impact on Helsinki, much less than the other case cities. Looking at transport impacts in Figure 5.17 and Figure 5.18, the policy resulting in the most decrease in the home work travel distance, average travel time and decreasing home to work travel distance is increased car use costs (policy 411 in the figure). The policy which results in the most improvement in the share of public transport is a reduction in public transport fare (policy 512 in the figure).

The highest impact is on Helsinki, although cordon pricing and increased car use costs are also fairly effective in increasing public transport share for all three case cities, and increased car use cost is most effective in increasing public transport share for Stuttgart. The policies provide more consistent results on transport impacts than the impacts of the policies on jobs and population, but even so variations exist among the case cities. For environmental policies the biggest decrease in CO^2 emissions comes from cordon pricing in Figure 5.18 – again the average is distorted by a very high result for Helsinki. Increasing car use cost is more effective for Brussels and also for Stuttgart in reducing CO^2 emissions. Cordon pricing has almost no impact for Stuttgart.

Variation of the number of households in the urban centre



Variation of the number of households in the urban zones



Variation of the number of jobs in the urban centre

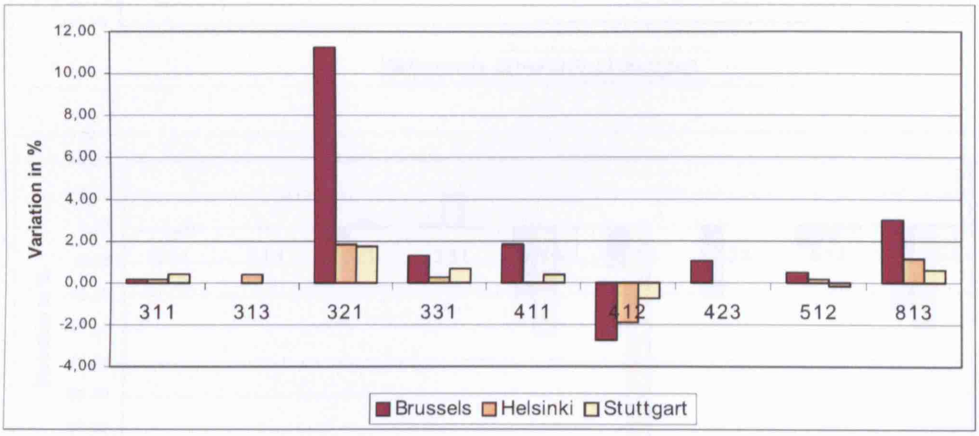


Figure 5.16 Relative variation in households in the urban centre, households in the urban zones and jobs in the urban centre

Variation of the number of jobs in the urban zones

Variation of the home-work travel distance in the study area

Variation of the total car mileage in the study area

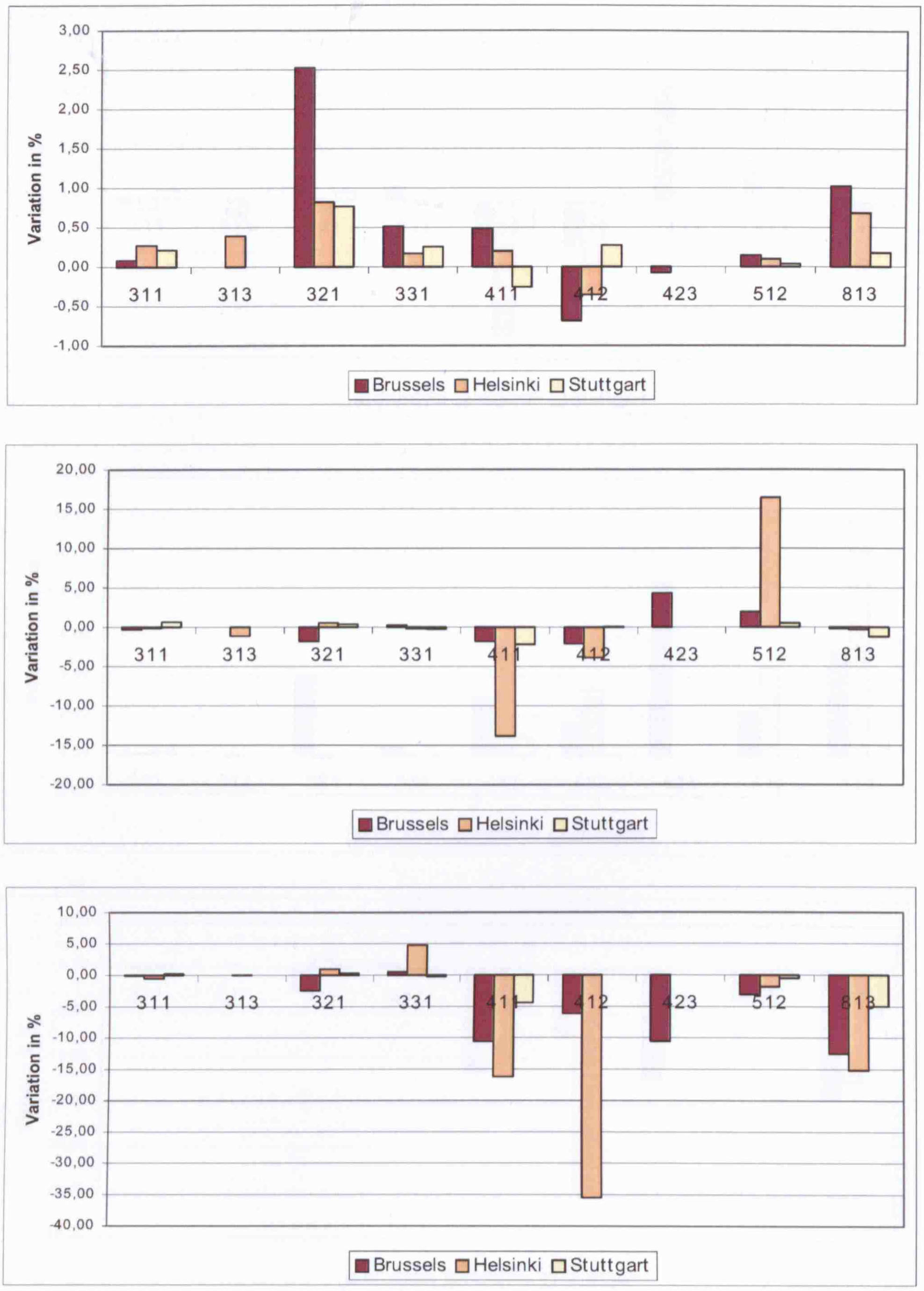


Figure 5.17: Relative variations in jobs in the urban zones, car mileage and travel distance

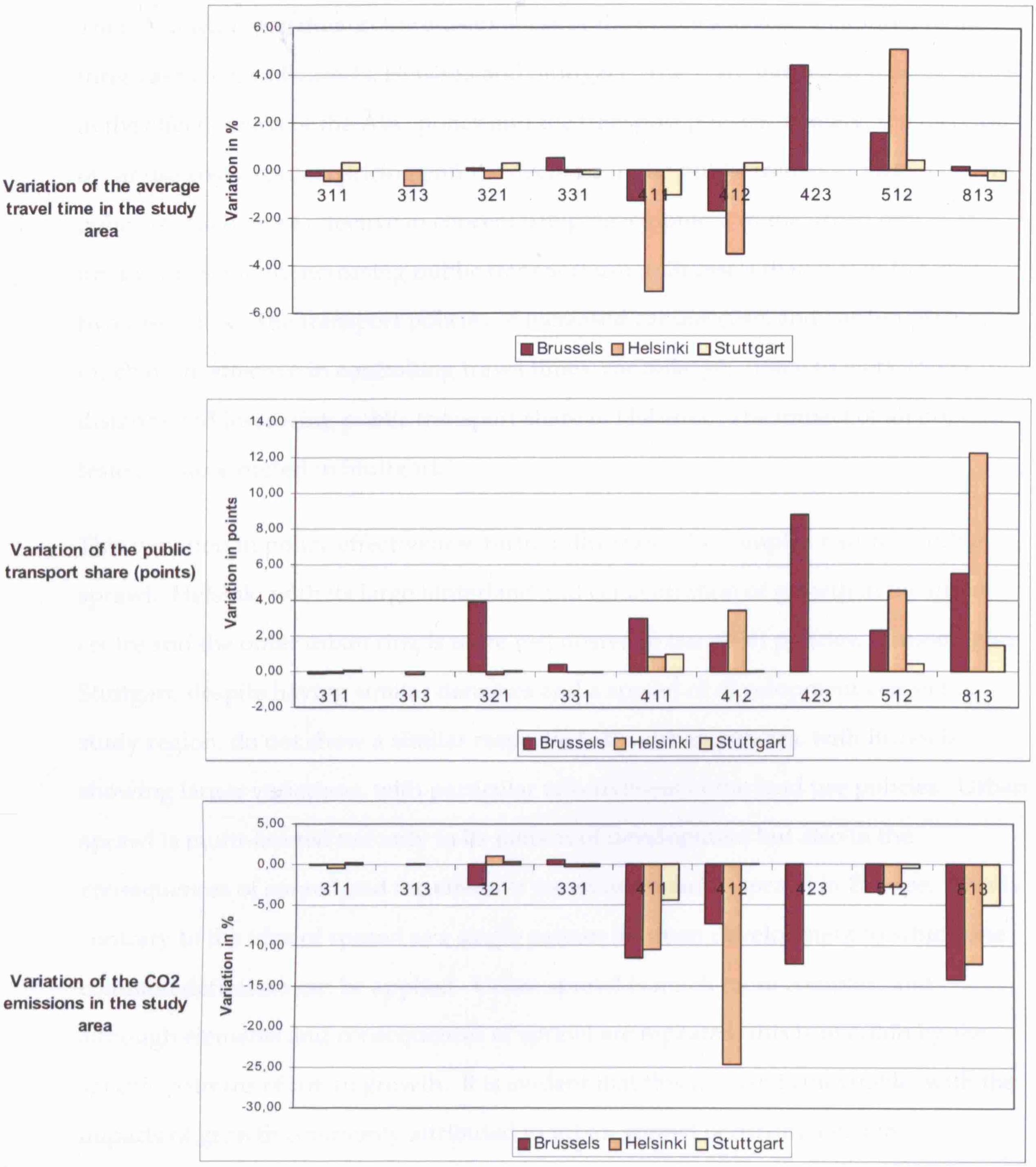


Figure 5.18: Relative variation of average travel time, public transport share and CO_2 emissions

5.5 Summary

There is a wide variation in the effectiveness of the policies to combat sprawl in the three case cities of Brussels, Helsinki and Stuttgart. There are particular discrepancies in the effectiveness of the ABC policy and the transport policies, namely, the increase of car use costs, cordon pricing and the decrease in the public transport fare. The ABC policy is much more effective in concentrating development in the urban centre and urban zones and in increasing public transport use in Brussels than it is in the other two case cities. The transport policies of increased car use costs and cordon pricing are much more effective in controlling travel times, car mileage, home to work travel distance and increasing public transport share in Helsinki. The impact of all policies tested is more muted in Stuttgart.

This variation in policy effectiveness further illustrates the complex nature of urban sprawl. Helsinki with its large hinterland and concentration of growth in the urban centre and the outer urban ring is more responsive to transport policies. Brussels and Stuttgart, despite having similar densities and a spread of development across the study region, do not show a similar response to the urban policies, with Brussels showing larger variations, with particular effectiveness of the land use policies. Urban sprawl is multi-faceted not only in its pattern of development but also in the consequences of sprawl and the effective measures to tackle sprawl in Europe. This is contrary to the idea of sprawl as a single pattern of urban development to which one common definition can be applied. Urban sprawl is much more complex, and although elements and consequences of sprawl are repeated, this is overlain by the specific patterns of urban growth. It is evident that this growth is inevitable, with the impacts of growth commonly attributed to urban sprawl occurring even in concentrated and compact urban areas.

Chapter 6

Defining Measures of Sprawl

6.1 The Role of Measures in Defining and Analysing Sprawl

The assessment of sprawl in the case cities of the SCATTER project has already revealed a complex phenomenon with experts in the regions often unable to agree on the patterns and consequences of this type of urban growth. Spatial measures based on form and function have been seen as one method of identifying the specific land use patterns of urban sprawl (Besussi and Chin, 2003; Chin, 2002). The findings of the SCATTER project however suggest that urban sprawl is a complex phenomenon that is an integral element of modern urban growth. Identifying sprawl is therefore more than the identification of specific conditions of land use at a specific scale, and measures of sprawl are therefore unable unambiguously to pin down *the* characteristics of sprawl and its form. As such, the identification of sprawl cannot be separated from its political dimension, with the suitability of the measures used subject to the emphasis of interpretation and the dimensions of interest to local administrators and land use authorities. However, an empirical definition of sprawl is often seen as a way of providing a method for clarifying definitions of sprawl and identifying sprawl empirically.

Previous attempts at measuring sprawl have assumed that sprawl is a phenomenon that can be measured consistently. The measures used have been applied across a variety of scales with little agreement on how this influences the identification of sprawl. For instance, Galster et al. (2001) see the urban area as a more suitable scale for the assessment of sprawl than the larger metropolitan statistical area, due to the latter's inclusion of rural areas which are not functionally connected to the urban core.

The SCATTER project has shown that this is not necessarily the case in Europe as urban sprawl has been identified in the rural hinterlands of Rennes and Helsinki. Other studies such as that by Ewing et al. (2002) provide little discussion on the choice of study area, while studies measuring the compact city use the administrative district as an approximation of the urban area (Burton, 2000, 2002; Burton et al., 2000). There has been little which can be translated to the selection of the study area most suitable for the examination of urban sprawl. Measures of sprawl have also been limited to administrative units with the study area defined based on densities seen as suitable for urbanization. Behind this is an assumption that sprawl is a specific land use pattern that can be identified at the most appropriate unit of analysis. Given that sprawl operates at a variety of scales, it is necessary to understand how the measures of sprawl are influenced by the unit of analysis.

The findings of the SCATTER project (outlined in chapters four and five) have found that the identification and definition of sprawl is dependent on the perspective of the municipality (for instance, cities can be seen as nodes in a polycentric network, rather than separate physical entities), the coordination of authorities, and the level of regional planning. The spatial scale at which urban sprawl is observed can heavily influence the identification of relevant issues and the selection and design of suitable indicators. It is also crucial to select the proper territorial scale for policy design and implementation in order to tackle urban sprawl. In addition, the most appropriate scale is related to the question of institutional barriers and modes of cooperation between different institutional players – often the main influence in deciding the most appropriate area for tackling sprawl.

There is therefore no one most appropriate unit of analysis and as such it is important to understand how the measures of sprawl operate over differing spatial scales. The measures used in the SCATTER project also separate density and concentration as measures of sprawl, while these characteristics are both integral to an assessment of urban sprawl. The measures explored in chapters six and seven examine changes in the identification of sprawl using simple aggregate density measures, measures which examine interactions of concentration and density at a neighbourhood scale and the use of land use measures. These chapters explore the impact of the type of measure and the scale at which the measure is applied in the identification of sprawl. The measures were applied to 44 of the counties of England, and corresponding urban areas, travel to work areas and districts, and to a sample of 11 of those areas. The measures were compared in terms of their ability to identify sprawl at differing spatial scales. This chapter outlines the definition of the measures and their suitability for measuring sprawl in a European context, while chapter seven discusses the results.

6.2 Issues of Scale

Issues pertaining to scale of analysis have been discussed in chapter three with reference to the polycentric city. Consideration of urban sustainability places the city as a system in relation to its regional background. As cities grow they use the resources of their region, thus affecting areas distant from their immediate location, with their health in turn being dependent on the region as a whole. This tendency is increased by processes of migration and growth of the cities which spill across their administrative boundaries (EEA-DG-JRC, 2002). The selection of study areas for the thesis examines measures of sprawl across four spatial scales – based on administrative boundaries and functional boundaries, which encompass the city centre and its immediate suburbs, and also the larger area or hinterland more relevant to the intra urban polycentric region.

Cross scale urban dynamics have been discussed by Dietzel et al. (2005) acknowledging differences in causal factors of urban diffusion at changing spatial scales. A street scale will highlight neighbourhood social and economic factors to a far greater extent than at a city wide or metropolitan scale. Indeed, " most mode based studies of urban growth follow the 'one scale, one extent' mantra that has guided research into urban growth dynamics for so long, the cross-scale dynamics of the urbanization process have not been directly addressed." (Dietzel et al., 2005, p.233) . It is precisely this issue which is examined in this research with scale defined as a change in geographical extent, rather than a change in the scale of the data used, along the city wide to metropolitan scale.

The issue of scale can also be linked to the Modifiable Areal Unit Problem (MAUP) (Openshaw, 1984). MAUP consists of both a scale and an aggregation problem, in which inferences about the data are altered when there are changes to the groupings of the units at different scales of the data collection areas. Areal units of collection such as enumeration districts are arbitrary and have little geographical meaning; thus different areal units can be just as meaningful in displaying the base data. The difficulty is that the statistics produced from the resulting aggregations vary with the units selected. This is particularly evident for statistics examining correlation and variance. Statistical changes resulting from the MAUP have been demonstrated in many studies, Openshaw and Taylor (1979), for example, compare the percentage of the population voting Republican in the 1968 Congressional election with the percentage of the population aged over 60 for 99 counties in Iowa. By aggregating these data to six regions using different arrangements of the boundaries, correlation coefficients of Republican voters with age varied from -0.99 to 0.99. In other words, the results of the analysis were dependent on the manner in which the data were aggregated.

The aspect of MAUP most relevant to this thesis is the scale problem which occurs when data from a lower level of areal unit is aggregated to a higher spatial resolution, for instance aggregation from enumeration districts to ward level. The scale effect has been explored, together with analysis of the scale and aggregation effect in combination (Fotheringham and Wong, 1991). As a result of the scale effect, data aggregated at a coarser scale become increasingly averaged or smoothed as outliers within each area are merged with a larger subset of the data. In the case of sprawl, for example, aggregating data from the scale of another can change the interpretation from one where sprawl is quite apparent to another where it is not.

The scale effect of the MAUP ties in to the problem of ecological fallacy; where inferences are made that the characteristics relevant to the individual unit apply equally to an aggregate unit, such as an administrative area (Robinson, 1950). In statistical terms, " the individual correlations depend upon the internal frequencies of the within-areas individual correlations, while the ecological correlations depends on the marginal frequencies of the within-areas individual correlations...the within areas marginal frequencies which determine the percentages from which the ecological correlation is computed do not fix the internal frequencies which determine the individual correlation. Thus there need be no correspondence between the individual correlation and the ecological correlation" (Robinson, 1950, p.354).

Later work comparing correlations at the individual household level and the census district level provides further detail of these differences. Statistical differences in the relationships between areal units can be seen in the correlation coefficients which can be expected to have larger absolute value than individual level correlations, with shifts in sign from positive to negative (Openshaw, 1984).

6.3 Quantifying Urban Processes: Learning from Urban Indicators

Early examinations of indicator development focus on acceptance of indicators within decision making. Innes (1975) suggests that to be successful, indicator development should sit within the context of public decision making, incorporating and reflecting public opinion. Secondly, to be successful, indicators need to be institutionalised, the concepts and methods must be accepted, with the indicators having an accepted place in policy making, not subject to the whims of politicians.

Later work has focused on approaches to indicator development within a variety of contexts. For instance, one justification of indicators has been to quantify and simplify complex processes, and to translate data and statistics into a form which is readily understood. The relevance of the indicator depends on the definitions used, continued relevance over a period of time, the level of detail, geographical scale and time period to which they are applied, their compatibility with each other and their relevance to the context in which they are used, namely the objectives and priorities of the users (Coombes and Wong, 1994; Lawrence, 1997).

6.3.1 *Indicator Projects in Europe*

One of the most investigated areas has been the development of specific indicators for the sustainability of urban areas. Models and programs of indicator development include the OECD PSR or Pressure State Response model (OECD, 2001a, 2001b), the EEA DPSIR model in connection with the 5th Environmental Action Programme, the Commission on Sustainable Development(CSD), United Nations Division for Sustainable Development (2001) sustainability indicators and the European Common Indicators Project (EU Expert Group on the Urban Environment, 2003) which involves indicators for sustainable policy making.

Although these programs are potentially informative, they remain focused on the thematic and temporal dimension with little application to spatial distribution. Other aspects of current indicator programs which lack applicability to identification of urban sprawl are discussed below. One aspect is the basis of indicator programs in sectoral analysis. The OECD, for example, provides measures at the city level targeted to individual sectors such as energy, housing and the environment. The indicators use summary statistics of direct data aiming to identify differences in the space of the city. However little connection is made between sectoral indicators. Indicators for complex concepts which combine information from multiple sources are rare, and it is this type of quantification which could provide a starting point for measures of urban sprawl. The process of indicator development is also highlighted as being of equal importance as the indicator itself – and in this sense the debate on indicators is seen as shaping policies and as a way to lead to consensus on policy (Innes and Booher, 2000).

The programs above also develop sustainability indicators reflecting social and environmental impacts, relevant to the costs of urban sprawl, in addition to traditional economic indicators. However there has been relatively little development of integrated multidisciplinary approaches, most useful to concepts of urban sustainability and sprawl (EEA-DG-JRC, 2002).

One example of work on spatially based indicators relevant to urban sprawl is the Murbandy/Moland project which examines aspects of urban growth and settlement patterns (EEA-DG-JRC, 2002). The project focuses on the development of a European wide dataset for urban areas which records urban land cover characteristics, using this to develop spatial indicators of the extent of Europe's urban areas, their progress towards sustainability and to model urban growth scenarios. The project has been expanded under MOLAND to identify fast land use dynamics and to identify regional and sub – regional territorial and environmental impacts.

Indicators used by the Murbandy/Moland project are based on earth observation data which allows for creation of dynamic indicators and observation of change over time. The project focuses on global indicators such as total artificial areas, change in artificial areas, loss of agricultural land, railway density, commercial areas as a percentage of total urbanised area, and green space as percentage of total urbanised areas. In addition a spatial indicator was calculated to identify change over time from agricultural and natural areas to artificial surfaces. These measures are applied to a study area for each case city based on the inner urban core, plus a buffer calculated as $0.25 * \sqrt{\text{Core Area}}$, which roughly doubles the core area. In some cities, the core area was extended to embrace a regional dimension. However, for the most part cities are identified as moncentric entities with interest in the change around the main centre.

The Murbandy/Moland project examines the fragmentation of the landscape using landscape structural analysis with the focus on examining the pattern of development at a neighbourhood level using measures, namely, area metrics, patch density, patch size, edge metrics, shape metrics, core area metrics, nearest neighbour metrics, diversity metrics and contagion and interspersion metrics, which examine the pattern of fragmentation or clustering in the urban area. There is a particular focus on the measure of total urban edge and green edge index developed for the project, which is used to identify land use classes adjacent to the urban area. This is used to monitor, for instance the impact of traffic corridors on residential areas, and access to recreational facilities.

The project is of interest for its use of remotely sensed data which provides data for the study of land cover/land use characteristics of an urban area and for study of change over time. The focus is on change in density and extent of uses, rather than on the examination of patterns of growth. Here we will take one of our case cities and examine the use of land cover data for identification of land cover/land use patterns pertinent to urban sprawl in the Bristol area, highlighting the suitability of fragmentation metrics for identification of urban sprawl in polycentric urban areas.

6.4 Data

The first section explores aggregate density measures utilizing data from the 1991 Census of Population in England and Wales. The study falls in the unfortunate position of having been conducted just after collection of the 2001 census and just before the release of the 2001 census results and associated products. Certain derived products such as travel to work areas for the 2001 census were not produced in time for this study. While this is unfortunate, it does not negate the results, as a review of sprawl over time is not our main purpose. The data are fit for the purpose of comparison of measures of sprawl at different areal extents and examination of the suitability of measures of sprawl in the European context.

The census data used for the aggregate density measures are the census key statistics for population, households and employment. The statistics are aggregated from the enumeration district and ward level to the four geographical areas studied. These output geographies suffer from problems of wide variations in population size and geographical area, and lack homogeneity, encompassing socially diverse areas (Martin, 1998, 2000, 2002; Martin et al., 2001). The density measures used are primarily aggregate, and therefore difficulties of defining enumeration districts and wards for presentation of output statistics have minimal impact.

The census data do not allow for a fine scaled assessment of urban sprawl, which is necessary for examining patterns of concentration. The data used for this section is derived from the Ordnance Survey Code - Point® data, as of 06/07/2001. Due to inconsistencies in the dates of the census data and the Code - Point® data, differences between the three groups of measures cannot be directly compared. The data however are suitable for the main purpose of the study – evaluation of measures at varying spatial scales and extents, and allow for exploratory assessment of the suitability of the three types of data and related measures for identifying and monitoring urban sprawl.

The Code-Point data provides information at the unit postcode level where each unit postcode includes approximately fifteen addresses. It is not possible to provide an exact areal extent as the size of the postcode unit area will vary according to the density of addresses. The level of detail is finer than at enumeration district level where the average size is approximately 200 households or 400 people. Each unit postcode is associated with a number of delivery points which match the number of single occupancy addresses. The measures make use of the number of domestic delivery points and the number of non-domestic delivery points. A third set of measures uses data derived from the Corine land cover data set which will be discussed further in section 6.10.2.

6.5 Comparison of Geographical Areas

A comparison of measures at four geographical scales was conducted. This looked at two administrative areas and two functional areas, namely the county and districts in place at 1991, and the urban areas and travel to work areas derived from 1991 census datasets. The measures of sprawl examined in the thesis have originally been applied to urbanized areas, assuming a monocentric core, rather than to the larger travel to work or county area. Particularly in the US literature, the choice of area has been one which encompasses the major city and its immediate hinterland. These types of studies have avoided the metropolitan area as it was assumed that this will cover large, sparsely inhabited areas (Transportation Research Board, 1998)

Research examining the relevant spatial scale of study areas comes from the US literature, Wolman (2002) compares the census urbanized area to the metropolitan area, and finds both lacking as appropriate study areas for sprawl. The census urbanized area is defined as a continuously built-up area with a population of 50,000 or more, comprising one or more central places and the adjacent densely settled surrounding area, the urban fringe. This definition is based largely on population, rather than the land use based definition of the urban area defined in the UK by the

Office of National Statistics. The US census also defines the central place for that area as the most populous centre of the urban area. The central place is also the central city of the urban area.

The Metropolitan Statistical Area (MSA) is defined as one or more counties with a city of 50,000 or a census urban area with a total population of 100,000. The MSA also includes secondary counties that meet the specified level of commuting to counties with the main population concentration.

Urbanized areas in the US have been identified as excluding development at the urban fringe (below the required urban area density of 1000 persons per square mile), while the metropolitan area being county-based contains large outlying rural areas not functionally connected to the urban core. In both cases, this reflects a view of urban sprawl as a city level problem surrounding a monocentric core, ignoring the idea of a regional polycentric perspective on spatial development. The study by Wolman et al. (2002) identifies the most appropriate area for measuring sprawl as the densely populated urbanized core, adjacent urbanized area at densities below the urbanized area threshold of 1000 persons per square mile, and any territory linked through commuting ties. This is defined as the 'extended urban area, which allows for development beyond the urban area, with a density of one dwelling unit per ten acres, but excludes areas of agriculture, forestry and small villages. The operative definition is the census urban area plus outlying census tracts with 60 or more dwelling units per square mile and with 30 percent commuting to the urbanized area (Wolman et al., 2002).

The study is exploratory in nature and examines in detail differences between the urban area and the extended urban area for only five cities: Atlanta, Baltimore, Boston, Los Angeles and Washington, DC. It looks at percentage differences in the measures between the urban area and extended urban area, changes to the sprawl rankings among the five areas and examines the Spearman and Pearson correlation coefficients between the urban and extended urban area. It should be noted that the correlation shows only that as the value of a measure for the urban area increases so does the value for the extended urban area; it does not mean they have to be equal. The measure for the urban area for instance could still be larger or smaller than that for the extended urban area.

This thesis provides new material by examining both functional and administrative areas taking a larger scale study of all English counties. Additionally, both the urban area and extended urban area of the US study focus on a moncentric urban core, while the thesis examines European polycentric development patterns.

6.5.1 *Administrative Areas*

Two administrative areas were examined - the county and the district - defined by the 1991 county boundaries. This is in keeping with the 1991 census data and reflects the two tier administrative structure in place at that time. The 1991 county boundaries have subsequently been superseded by the 1997 county boundary revisions and shoud thus be seen 'virtual' county boundaries. The county was used to provide a level of coverage suitable for the inter urban area. The suitability of the county for a regional level of coverage is demonstrated by the Bristol case study in chapter four which outlines the interactions between the Bristol urban area and its sub centres in the regional structure plan (JSPTU, 2002). The former county of Avon has subsequently devolved to unitary authorities under the 1998 Local Government Reorganisation Act.

6.5.2 *Travel to Work Areas*

Functional definitions of regions offer an alternative for comparative analysis. Different land use regulatory schemes in Europe means there is little connection between the built-up area of cities and their functional area, and secondly increasing commuting distances means that the built-up area and functional area are likely to be increasingly separate from each other. The most common functional area definition remains the travel to work area (ESPRIN UK, 2000).

The travel to work areas (TTWAs) used are those created in 1998 using 1991 census data. The travel to work area methodology developed by Coombes (1998) groups wards together into areas which are self contained in terms of commuting. This is defined as the commuting population of which 75percent work in the area and of those working in the area 75 percent live in the area, with a working population of 3,500 or above, or with a working population of 20,000 or above and self containment of 70 percent.

TTWAs are defined purely in terms of the lack of commuting between places rather than the existence of commuting within them. TTWAs are one way of looking at patterns of flows or interactions in and around cities, and although commuting data reflects only journey to work patterns, it is the most readily available source of movements and interactions between areas and is used as a proxy for the local labour market area. One issue with TTWAs is that the average commuting distance for different occupational and social groups can vary widely. The use of the TTWA to differentiate one city and its hinterland from another is therefore subject to a variety of boundaries by occupational group (Coombes and Wymer, 2001). This is a useful geographical extent for the study of urban structure as it reflects the zones of influence of major settlement areas.

The algorithm works as follows. At stage one, potential travel to work wards are selected which are defined as those where the number of workers is greater than number of residents, and those with a high proportion of residents working in the ward. At stage two, the 'job foci' of the travel to work area is identified by grouping together interrelated wards from those identified in stage one. This was done using an iterative procedure based on the criteria of commuting flows. Wards were amalgamated to the ward with the largest commuting inflow, based on the strength of the commuting link, provided at least 10 percent of workers commuted to the main ward, and 1 percent of the main ward commuted to the candidate ward.

At stage three, proto travel to work areas were created by identifying a core job foci with 50 percent self containment, and merging wards and job foci with this area, according to commuting links. At stage four, all remaining wards were allocated to the proto travel to work areas depending on commuting links, and the final stage reallocated proto travel to work areas which did not meet the criteria of self containment to areas which had the closest commuting links. Further details of the algorithm can be found in Coombes et al. (1986).

The travel to work areas were selected as the area of study for best representing the functional interactions between cities in a polycentric urban area. This is especially important given that traditional areal units used to assess sprawl, such as administrative boundaries, are often of little relevance to social and economic units. For example, the city administrative boundary may not cover a large part of the suburban development which has strong functional ties to the traditional city (Clawson, 1971). This representation of the self contained labour market area reflects the commuting patterns within the region. From the framework of urban sustainability discussed in chapter three, congestion and level of vehicle miles travelled is one of the main costs of urban sprawl. The travel to work area thus covers a geographic unit of analysis which includes areas impacting on the central city and likely to be affected by the costs of sprawl associated with commuting.

6.5.3 Urban Areas

The second functional area used is the Office of National Statistics (ONS) 1991 definition of urban areas. Urban areas in the UK have been defined according to a number of methods based on administrative areas, urban land use and population size and the social and economic characteristics of places (Office of the Deputy Prime Minister, 2002). There is no single official definition, although the definition most commonly used is the ONS 1991 urban areas which are based on land use/population criteria. These are independent of changes to the administrative boundaries and being derived from the extent of urban areas indicated on Ordnance Survey maps is directly related to land use policies.

The enumeration district was used as the minimum mapping area. Areas of urban land use were derived from Ordnance Survey maps with an enumeration district classified as urban if its population weighted centroid fell within the area of urban land. Following on from this, urban land was grouped into urban areas where areas of urban land covered four or more enumeration districts and contained a population of at least 1,000. Urban areas were further agglomerated into larger continuous urban areas where urban areas of 20 hectares were also less than 50 metres apart.

Urban land is defined as that which is 'irreversibly urban in character' as defined by the National Land Use classification. It includes permanent structures, transportation corridors, transportation features, mineral workings and quarries and any area completely surrounded by built-up sites. The ONS definition of urban areas was deemed to be suitable for the purpose of the thesis as it is the land use characteristics of a place which are relevant to the study of urban sprawl. The urban area definitions consisted of aggregated urban areas, which could be divided in sub divisions. For this thesis the sub division of each urban area with the largest population was selected for study. A sub division was used for study as the aggregated urban area was polycentric in form. However, the urban area was intended to examine sprawl around in an area with a monocentric form, while the polycentric functional areas would be studied using the travel to work area definitions.

6.6 Details of Area Selection

This section provides details of the selection of individual areas for comparison. Drawing on results from the SCATTER project and the Bristol case study, the 1991 counties were selected as one potential area for the study of sprawl. All English counties were selected with the exception of London and the Greater London area, as these represented an atypical case in form of levels of population and employment density.

The largest urban area within the county was chosen with urban area subdivisions considered as separate entities. The urban areas were assigned to counties using the 1991 Engwal Area master file, which is a census look up table which indicates howthe the enumeration districts fit into higher level geographies. In this case, how the four levels of 1991 census geography in England and Wales (counties, districts, wards and enumeration districts) fit into other statistical, administrative, electoral, postal and morphological spatial units. The district, travel to work area and county surrounding the urban area were then selected. Appendix A presents various spatial configurations illustrating the relationship among the four areas.

6.7 Employment Subcentres

The measures of sprawl examined required identification of urban sub centres, but this data was not available for all areas used in the study. As such urban sub centres were identified using a method for identification of employment sub centres developed by Giuliano and Small (1991), the details of which are discussed below. The focus of the thesis however is not in the identification of employment sub-centres, so a standard method employed by Giuliano and Small (1991) was used in order to examine the applicability of the measures of sprawl within a polycentric urban area. Employment data was derived from the 1991 census special workplace statistics set B, which gives the employed population by workplace, including those working at home. Table WB3 was used to give total employees and self-employed, by workplace, which is the number employed in each ward who work in that ward. The set is a 10 percent sample, which was scaled to 100 percent multiplying the sample by 10).

The first method examined is relatively simple based on employment density cutoffs where an employment centre is defined as a contiguous set of zones, each with a density above a cutoff D, with total employment above a cutoff E over the overall mean (Anderson and Bogart, 2001; Giuliano and Small, 1991; Small and Song, 1994). Giuliano and Small (1991) developed what is now regarded as the standard method for identification of sub centres. Their study of Los Angeles selects a minimum employment density of 10,000 with a density of 10 employees per acre. This method relies heavily on local knowledge for selection of the cut off values, and as a result the densities applicable to the US study would not necessarily identify excess employment in the UK, particularly given the high base level of employment density in the city of Los Angeles.

In this case, the employment cutoff of 10,000 was selected with densities of, at or above 5, 7 and 10 employees per acre, and also at or above the regional average density

(Cervero and Wu, 1997). Cevero and Wu have adapted the method of Giuliano and Small for the San Francisco Bay area by defining employment centres as a continuous set of census tracts with employment densities that exceed the regional average. The regional average was calculated for each county per acre, as total employees divided by total acreage, with an employment cutoff of 10,000 for each sub centre. The employment cutoff of 10,000 was retained based on an initial study of the Bristol region which eliminated small non-contiguous areas not identified as belonging to Bristol, Bath or Weston-super-Mare.

Further research could investigate other methods of identifying employment sub centres which are outlined below and the resulting impact on measures of sprawl. These methods address the shortcomings of the density based approach used by Giuliano and Small (1991), which requires local knowledge thus limiting the transferability of the method. In addition to the problem of local knowledge, subcentres based on employment cutoffs are dependent on the size of the unit of observation. Tracts that are too small result in a highly peaked surface of isolated pockets of high density employment in an otherwise residential area. Large tract size on the other hand, smoothes over employment density peaks with fewer subcentres identified. However, for the purpose of the thesis, the use of the density based approach used by Giuliano and Small (1991) is sufficient, as the impacts of sprawl are heavily dependent on population and employment density.

Potentially useful methods include that of McMillen (2001, 2003, 2004) which uses a non-parametric procedure to estimate employment subcentres. This has the advantage of suitability for different sized units of analysis, removing the need for local knowledge to identify the appropriate level of employment density and adjusts for distance to the CBD, as a higher rise in employment density is required to produce a sub centre closer to the CBD. The non parametric approach employs locally weighted regression to identify sites with cut-off points for employment density which varies across cities, where the explanatory variables are the geographical coordinates of potential sites. Locally weighted regression provides an advantage in that more weight is placed on nearby observations when estimating a predicted value for the natural logarithm of employment density at a specific site, with the explanatory variables being the geographical coordinates of the potential sub centres. The LWR produces an initial smooth surface of values of the natural logarithm of employment density (y) over space, dependent on the coordinates of any sites distance north and east of the city centre. A large bandwith is used where the nearest 50 percent of observations receive some weight in estimating the smoothed value of y at a site. Potential sub centres are identified as sites with residuals significantly greater than zero or, in other words, where densities greatly exceed the initial smooth set.

It should be noted that Fotheringham et al. (2002) argue that the parameter selected for the bandwidth plays a large part in the outcome of the model. The bandwidth can be chosen in two ways, either using an adaptive kernel where a set number of data points is covered by the kernel, or by a fixed bandwidth where the kernel is given a fixed diameter. In McMillen's method, an adaptive kernel is used which has an advantage when data points are sparse. Too small a bandwidth causes the regression to 'wrap around' the data point, providing an estimate for each data point, while too large a bandwidth causes a global regression, covering all of the data points. Calibration of the model based on bandwidth selection is essential and should be justified. Otherwise the model replaces difficulties in selection of density cutoffs with equally arbitrary selection of a bandwidth which will affect what is produced as a local peak in the employment density function.

However, use of LWR has an advantage over density cutoffs in that the initial smoothing eliminates the sensistivity of the results to size of census tract. It can detect local rises in the employment density function and it accounts for variations in density gradients across a metropolitan area. The need for local knowledge in identifying peaks is removed and replaced by the use of statistical criteria to determine if local employment peaks are large enough to be counted as subcentres. This procedure controls for overall patterns of density when identifying candidate sub-centre sites, so cities with high overall density require higher overall density to qualify as subcentres and minimum density levels can vary spatially within the county area. The city centre is taken as the ward with the highest employment.

Other work has also turned to the role of service type in the identification of suburban employment centres and the identification of the strength of suburban economies – an important distinction between urban sprawl and polycentricity (Berkoz, 1998; Coffey and Shearmur, 2002; Parolin and Kamara, 2003). This allows for comparison of growth of the new wave of suburbanization around traditional CBDs. Early decentralization in the 1970's involved back office functions as discussed in more detail in chapter three, with the movement out of standardized and routine activities, while high level functions remained concentrated in the CBD. More recent development has seen the diversification of the suburban economy, with growth shared between the CBD and suburban agglomerations. Recent work has attempted to measure the types of higher order services as well as the strength of suburban agglomeration economies and the extent of backward and forward linkages between suburban firms. Maps of the sub centres and centres identified are found in Appendix A.

6.8 Measures of Urban Sprawl

The thesis examines measures of urban sprawl using three types of measures: aggregate density measures, measures examining patterns of concentration of population and employment derived from the US literature on racial segregation, and measures based on land cover/land use characteristics derived from the landscape ecology literature. Three types of data are used, namely aggregate census data, point data derived from postcode geography, and land cover data from remotely sensed images. The study compares the measures among four geographical areas, exploring deficiencies in the geographical scale used to measure sprawl. Issues of scale and density which impact on the type of measure used have been discussed in chapters three and five.

6.8.1 Measures of Sprawl using Population and Employment Density

Basic measures of sprawl using aggregate densities looking at density across the study areas were examined as a base for comparison with further measures of sprawl detailed as follows (Burton, 2000, 2002; Burton et al., 2000; Craig and Ng, 2001; Ewing et al., 2002). Density is often used as a proxy for costs of sprawl, and as such plays a large part in identifying compact or sprawling development. Density is most commonly given in the measures of sprawl as dwelling per hectare/acre, or persons per ha/acre. In identifying urban sprawl, dwelling unit density does not reflect dwelling size which is an important factor in identifying environmental impacts of sprawl. Dwelling size is also related to population density as it reflects household size. Dwelling unit density is best suited to costs of sprawl such as infrastructure provision and environmental costs.

Population density is also relevant to impacts of urban sprawl, but is more suitable when considering impacts such as the population available to support public services, or transit ridership, and levels of traffic congestion (Churchman, 1999). Population density is also calculated using weighted population density, which takes into account variations in the density of sub areas when calculating density (Craig and Ng, 2001). The higher the conventional density, the smaller the difference with population weighted density. Higher density sub areas will have a more homogenous population distribution, as these sub areas will lack large sparsely populated areas, or unpopulated undevelopable areas. The areas with the widest divergence will be those sub areas with a large city combined with large rural areas. Those with the least uneven distribution would be areas with no large dominant cities with a uniform internal character. If there is a wide variation between sub areas, it may be preferable to sub divide an area and use groups of more homogenous sub areas. For instance, with an urban-rural split, sub areas can be grouped by density.

An important point in terms of the scale of the area studied is that population densities tend to decrease as the area considered increases. At larger scales, the amount of non residential use increases, lowering the residential density when looking at larger areas. This is often one of the reasons given in the literature for the use of a particular scale of study; however as discussed in section 6.1, urban sprawl is a complex phenomenon which is ultimately related to its political and administrative context. Therefore one cannot so easily select the area of study which best suits the dimensions of the measure.

The measures of sprawl examined reflect the characteristics identified in chapter three. Gross densities (pwd) have commonly been used as a measure of sprawl, despite the inability to account for variation in the distribution of population within the area – a key component of urban sprawl. Following on from this, the measures described in Table 6.1 represent attempts to identify the variations in population and household distribution using simple, aggregate methods.

Table 6.1: Measures of sprawl based on aggregate density

Measure	Description
pwd	Population weighted density. $$\frac{\sum_{i=1}^{n}(D(i)xP(i))}{\sum_{i-1}^{n}P(i)}$$ where D(i) is the density of persons / hectare of the ward, P(i) is the population of the ward
ldensp	Population density of the four least dense wards
mdensp	Population density of the four most dense wards
ldensh	Household density of four least dense wards
mdensh	Household density of the four most dense wards
less 0.5	Percentage of people living at densities less than 0.5 persons per hectare (50 persons per km^2)
0.5 - 5.0	Percentage of people living at densities between 0.5 and 5.0 persons per hectare (50 and 500 persons per km^2)
5.1 - 48	Percentage of people living at densities between 5.1 and 48 persons per hectare (501 and 4800 persons per km^2)
>48	Percentage of people living at densities greater than 48 persons per hectare (over 4800 persons per km^2)
pdcc	Population density within the central city
pdfr	Population density within the fringe
perpcc	Percentage of the total area population living within its central city
perpfr	Percentage of the total area population living within the fringe
rpd	Ratio of the central city's population density to the density of the fringe

The gross density measures -pwd, ldensp, mdensp, ldensh, mdensh - despite their limitations, have been used as measures of the compact city, with lower densities indicating higher levels of sprawl (Burton, 2000, 2002; Burton et al., 2000). Previous studies (Galster et al., 2001; Transportation Research Board, 1998) have limited measures of density to the urban area, as it is assumed that densities over larger metropolitan wide areas would include sparsely inhabited territory which is not sufficiently urbanized to count as urban sprawl. However, under a polycentric settlement pattern, high densities could be expected outside of the central city, interspersed with rural areas. As discussed in chapter four, experts interviewed in the case cities of the SCATTER project, particularly Helsinki and Rennes, identified sprawl in their case cities outside of the urban centre, and including the rural hinterland. In the pwd measure, the subdivisions and their densities are weighted by the population to provide a more accurate picture of the density, accounting for differences within sub divisions.

Measures based on differences in density (less 0.5, 0.5-5.0, 5.1-48, >48) attempt to account for the variation in density within an area. The measures identify the proportion of people within the area living at sprawling densities. The figures are derived from central government studies (Department of the Environment Transport and the Regions, 1998; Office of National Statistics, 2001) which identify densities less than 0.5 as rural or sparsely population; densities of 0.5 to 5.0 as low suburban density; 5.1-48 as high suburban density and over 48 as a transit supportive density. The densities are calculated at enumeration district level, and the percentages calculated as the sum of the population for all enumeration districts with population density < 0.5, divided by total population.

Measures based on density concentrations have been calculated for the county area only based on the employment subcentres described in section 6.7. This subdivides the aggregate density of an area into central cities and the fringe. The lower the density of the periphery, the higher the level of sprawl. The percentage of total area population provides a parallel measure. The ratio of population densities is based on the idea that a central city with much higher density than the surrounding fringe increases the likelihood of population moving out of the central cities to the fringe.

6.9 Measures Based on Population and Employment Patterns

More sophisticated attempts to measure sprawl based on indices of residential segregation have examined the population and land use patterns of the study area, thus allowing for differences in density across the urban area (Duncan and Duncan, 1955; Galster et al., 2001; James and Taueber, 1985; Massey and Denton, 1988; Massey et al., 1996; Taeuber and Taeuber, 1965). These measures are based on dwelling unit data derived from the Code-Point® data described in section 6.4. The urban areas are divided into quarter and one mile square grids. Low values represent higher levels of sprawl. Previous studies have applied these measures to monocentric cities, and the thesis adapts the measure of centrality for polycentric urban areas, and in addition makes use of postcode data for creation of the grids, where previously block data from the US census was used. These measures have the disadvantage of being affected by the size of the study area in that inclusion of large areas which are rural in character will affect the result of the measures. The extent to which this is the case in a polycentric environment is examined and the measures in section 6.10 address this problem in allowing land uses to be separated from each other, allowing for measures of sprawl which are not influenced by extraneous conditions. The following measures identified in Table 6.2 identify key dimensions of urban sprawl.

Table 6.2 : Measures of population and employment pattern (from Galster et al., 2001; Massey and Denton, 1988)

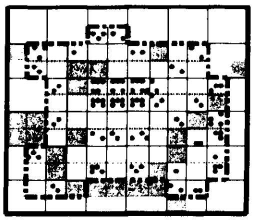
Measure	Description
continuity	Measures the degree to which land has been built on at urban densities in an unbroken fashion $\text{CONT(i) u} \sum_{s=1}^{S} [\text{D(i)s} > 9 \text{ Residences and 49 Employees} = 1; \text{zero otherwise}] / \text{S}$ [min = 0; max = 1] where CONT (i)u is the continuity of land use i over the entire urban area u, s is the ¼ square mile grid (1/4 square mile is equivalent to 0.64750 km^2), D(i)s is the density of land use i over area s, S is the sum of all ¼ square mile grids. 1 mile is equal to 2.589 km^2 As illustrated below a low level of continuity results in several areas of developable land (white) with residences and employment below urban densities.  **Leapfrog development – low continuity**

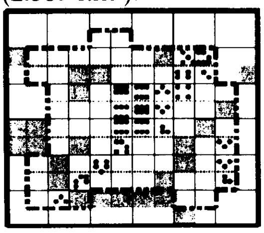
Table 6.2 (continued)

Measure	Description
concentration	Measures the degree to which development is located in a few square miles of the urban area, rather than spread evenly throughout. It is the proportion of residential development in areal units with above average density. Gives the share of development that would have to shift to achieve a uniform density.

$$DELTA(i)u = (1/2) \sum_{m=1}^{M} abs [T(i)m / T(i)u] - [Am / Au]$$

Where D(i)u is the density of land use i over the urban area, m is the 1 mile sq grid; M is the sum of all 1 mile square grids (1 mile is equal to 2.589 km^2), T(i)m and T(i)u are the total number of residential delivery points in m and the entire urban area respectively; Au is the area of the study area; Am is the area of the 1 mile square grid .

As illustrated below a high concentration of development, where development is located in only a few sections of the urban area, results in areas of high density per square mile (2.589 km^2).



Ribbon development – high concentration

Table 6.2 (continued)

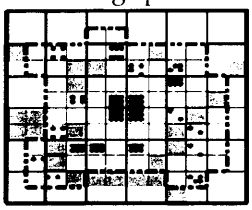
Compactness or clustering

Measures the degree to which development is concentrated within each square mile. High level of clustering indicates contiguous and closely packed residential areas. Low levels indicate scattering of residential development around the urban area.

$$COMP(i)u = \left[\sum_{m=1}^{M} \left(\sum_{s=1}^{4} [D(i)s - D(i)m]^2 / 4 \right)^{1/2} / M \right] / \left[\sum_{m=1}^{M} D(i)m / M \right]$$

Where m is the 1 mile square grid, s is the quarter mile square grid, D(i)s is the density of land use i over the quarter square mile, D(i)m is the density of land use i over the square mile.

As illustrated below high compactness results in development which is clustered in only 1/4 of the entire square mile, rather than being spread throughout the square mile.



Centrality or centralization

Centrality measures the degree to which residential and non residential development is located close to the CBD.

$$CEN(j)u = \sum_{h=1}^{H} [T(j)h\text{-}1][Ah] - \sum_{h=1}^{H} [T(j)h][Ah\text{-}1]$$

where Cen(j)u is the centrality of land use j over the urban area, Ah is total area at distance h from the CBD, h is the distance of the concentric ring at distance h from the CBD, H is the total of all concentric rings, T(j)h is the total land use j in ring h

As illustrated below, a high level of centrality results in development which is clustered around the urban centre, or as for this thesis, around the urban centre and all employment centres.

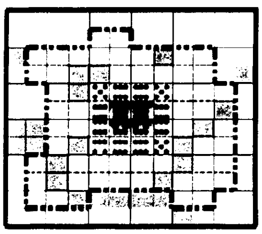


Table 6.2 (continued)

Diversity

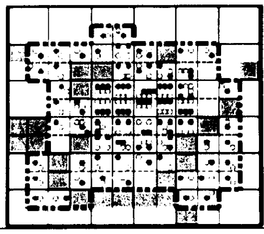
Measures the degree to which numbers of residential and business uses exist within the same area. This measures calculates the average density of a particular land use in another land uses area.

$$DIV(j \text{ to } i) = \sum_{m=1}^{M} \left(D(i)m \times [D(j)m \,/\, T(j)u] \right) / D(i)u$$

[min = 0; max = max D(i)m observed in any area occupied by j]

where m is the 1 mile square, D(i)m is density of land use i in the 1 mile squre, D(j)m is the density of land use j in the 1 miles square grid,T(j)u is the total of land use j in urban area, D(i)u is the density of land use i in the urban area.

As illustrated below a high level of diversity results in high numbers of residential and business use within each square mile.



The measure of continuity identifies areas of high density, given as nine residences and 49 employees in the quarter mile square grid, in relation to the urban area as a whole. It measures the extent to which land is developed in a continuous fashion. Density is used solely as a means of establishing which areas are below the threshold which is considered developed. An area of continuous suburban sprawl will have a high score of continuity while areas with high densities but large areas of undeveloped land (leapfrog development) will have low scores of continuity.

Concentration measures the extent to which development at a high density is located in a few areas of the urban landscape, as opposed to a more even distribution across the landscape. Occupation of a small share of the total area results in concentration. Residential areas that are few in number yet small in area are more concentrated. It examines the distribution of development across the urban landscape but the density of that development is not taken into account. A low density development located in a small area of the urban landscape would have the same score as a high density of development located in a similar area. Lower concentration indicates higher levels of sprawl.

Compactness measures the concentration of an area at a neighbourhood level - within the one miles square grid. An area may be developed evenly (have a high level of continuity), have high levels of concentration across the urban area, yet low compactness. High levels of clustering indicate less sprawl. The measure of centrality indicates the extent to which development has diffused across the urban landscape, away from the urban centre. It measures the proportion of development at a certain distance from the urban centre. The proportion of development is calculated using buffers one mile apart around the central city and its subcentres and this adjusts the original measure which focuses around a single CBD to account for polycentric areas. These buffers are used to calculate the cumulative proportion of residential development and land area at increasing distances from the centre.

The measure of diversity looks at the separation of land uses at the neighbourhood level within the one mile square grid. High degrees of diversity indicate higher levels of mixed use and less sprawl. Diversity can be seen as the extent to which business address points are exposed to residential address points within each square mile. It is calculated as the minority weighted average of each spatial units minority population

6.10 Measures Based on Land Use Pattern

Measures based on land use pattern come from the remote sensing tradition. Remote sensing data and techniques related to the measurement of urban sprawl have been used for determining urban change, and the monitoring of urban areas (Buchanan and Acevedo, 1996; Chen et al., 2000; Darvishzadeh, 2000; Ji et al., 2001; Kressler, 1996; Nigam, 2000; Ward et al., 2000; Yeh and Li, 2001).

6.10.1 The Remote Sensing Tradition

Remotely sensed data provides a potentially rich source of temporal data, useful for the study of change over time which is not tied to administrative units. The main difficulty is that remote sensing systems are adept at detecting land cover rather than land use. Land cover refers to the vegetation and artifical surfaces while land use relates to the activities and uses of these buildings and land. Information about land use is traditionally inferred by a human interpreter using supplemental information. For example the land cover of the urban or built-up area can be classed at a land use level into single family units, multi family units, group quarters, residential hotels, mobile home parks and transient lodgings (Anderson et al., 1976). The most common data used are Landsat TM with a spatial resolution of 30m, making remote sensing most suitable for a larger scaled area. The most common use of remotely sensed data is identification of changes in transition between urban land uses and areas of agriculture and forestry, although studies at finer resolutions such as 1:25000 aerial photos have been carried out (Nigam, 2000)

Attribute information useful for the identification of costs of sprawl are lacking, so while remote sensing techniques can determine patterns of sprawl, there is little record of housing or employment type, or of functional characteristics important to evaluation of the costs of sprawl. Attribute information has been combined with remotely sensed data in a bid to provide richer data sources. For instance, Ryznar and Wagner (2001) combine Landsat vegetation change images with variables representing physical quality of life from the census, such as median income, ratio of children to women, ratio of males and females, and ratio of mid age adults to young adults data.

Combinations of GIS and remote sensing have been used to overcome this (Fazal, 2001; Herold et al., 2003; Herold et al., 2002; Ji et al., 2001; Wilson et al., 2003; Yeh and Li, 2001). For example, Yeh and Li (2001) combine GIS and Landsat TM data to measure the degree of spatial concentration or dispersion of a geographical variable, with subsequent identification of urban sprawl identified from patterns of concentrated low development, dispersed medium development, and highly dispersed development.

Mesev et al. (1996) discuss the use of ancillary information to improve land use classification of multispectral images. Attribute information from the census is associated with remotely sensed images using a surface model based on disaggregated enumeration district centroids or postcode data. The census data was used to determine the proportion of each dwelling type, adjusted to account for spatial size of dwelling units. The adjusted proportion was then applied to determine the areal proportion of each type, and these proportions used to determine the a priori probabilities of the Bayesian decision rule applied to the maximum likelihood classifier. In this instance, spatial models of housing density were used to identify the number and location of training samples used to identify detached, semi detached, terraced and purpose built apartments, with building type being associated with a particular residential density. Much more detailed information could then be gained from the image. The second use was to verify the classification and identify misclassified pixels between residential and non – residential uses.

6.10.2 Remotely Sensed Data used for Measuring Sprawl

Specific work generating measures of sprawl has been conducted by Sutton (2003) using Defense Meteorological Satellite Program's Operational Line-scan system (DMSP OLS) satellite images, which measure the radiance emitted from city lights, to determine urban extent when combined with a grid of population density derived from census data. This indicator of sprawl however, remains an aggregate measure of per capita land consumption over the urban area, which is adjusted for population size in the urban area.

Mesev et al. (1996) show how urban form and density can be measured from remotely sensed data using fractal geometry. This summarizes spatial form by assuming that densities of urban development at different distances from fixed points can be modeled using power functions. While fractals can summarize the form of the city they do not specifically measure the extent of outward growth or sprawl.

Other modeling approaches include that of Wilson et al. (2003) which defines a typology of growth, based on relations between developed and non – developed pixels. Infill growth is defined as a conversion of a non – developed pixel to developed and surrounded by 40 percent developed pixels; expansion or fringe development is defined as a non - developed pixel converted to developed and surrounded by no more than 40 percent developed pixels; outlying growth is the change from non-developed to developed and surrounded by non - developed pixels. This can be isolated, linear or clustered. Isolated shows non developed pixels at some distance from developed areas; linear shows a linear set of pixels surrounded by non - developed land; and clustered shows a cluster of developed pixels.

6.11 Landscape Ecology Measures

An alternative approach is provided through measures used within landscape ecology to identify patterns within the landscape. Similarities between landscape ecology and urban sprawl lie in the idea of the urban environment as heterogenous patches of land use development. Patches at one scale can be composed of various regions city, inner suburbs, suburbs, exurban and hinterlands, and further divided into land use types at finer scaled levels of the patch hierarchies. Each hierarchy reveals different processes and functional relationships between and within scales. The measures examine the physical arrangement and interaction of the patches of land use development, the context or location in relation to the rest of the landscape, the level of connectivity or continuity within the landscape, and the heterogeneity of patches in a landscape (Alberti et al., 2001; Zipperer et al., 2000)

Landscape ecology measures have been quite widely used in (Forman, 1995; Forman and Godron, 1986; O'Neill, 1988) and the measures used in the thesis are class and landscape measures. Class measures examine the patterns formed by each land use class in isolation while landscape measures examine the interacting mosaic of patches across all classes. Each landscape consists of a matrix and several patches. The matrix is generally the most extensive and connected landscape element type. For this study, the landscape was characterized by three patches, residential, commercial and industrial and non – urban consisting of agricultural and non-developable land. The use of class-based measures allows for the isolation of patterns of residential land use from commercial and industrial. There is no real matrix, so the no data value is assigned as the background. An alternative would be to assign non-urban land as the matrix; however, it was felt that this element was important in its own right as an element of the landscape of urban sprawl.

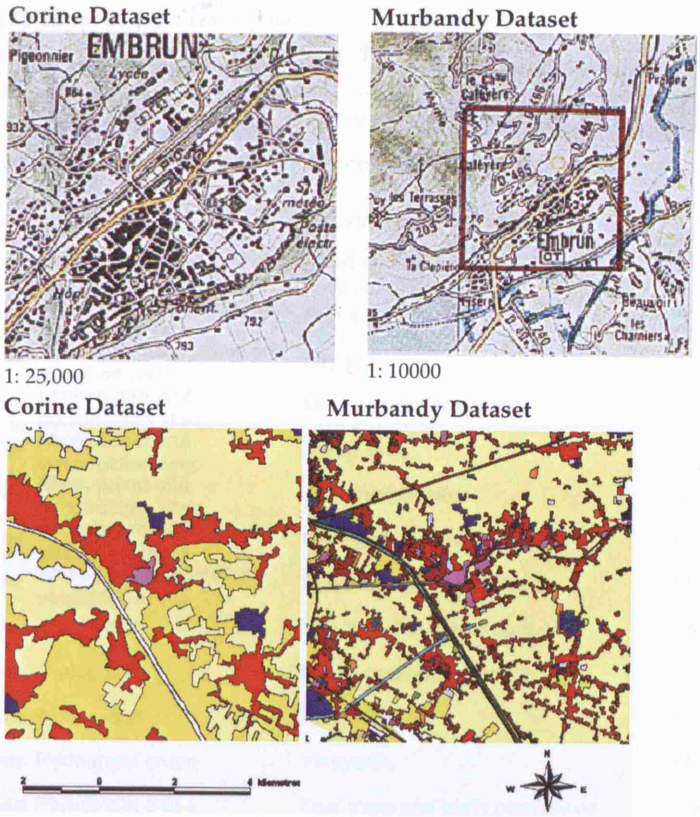
These spatial metrics provide a global summary descriptor of the pattern of the landscape. The representations of spatial heterogeneity are dependent on the spatial resolution of the data, classification of the remotely sensed data and the extent of the area. Some issues affecting the validity of landscape ecology metrics are the scale of measurement or resolution, and its extent or size of the study area, which affects spatial pattern and heterogeneity. For instance, Anas et al. (1998) shows how clusters of employment density in Los Angeles county disappear at coarser levels of spatial resolution.

The measures were originally developed for landscape ecology and their use for describing urban areas is fairly new (Herold et al., 2003; Herold et al., 2002). One project using landscape ecology metrics for urban patterns is the Murbandy/Moland project (EEA-DG-JRC, 2002) which examined fragmentation in the landscape. A similar project examining the process of urban growth through landscape ecology metrics is that of Dietzel et al. (2005) who examined the Houston Metropolitan Area over a 30 year time period using landscape ecology metrics to monitor diffusion of development over the urban area.

The data in this thesis is the "Corine V Land Cover (CLC90) 100m version 12/2000" available from the the European Topic Centre on Terrestrial Environment (Bossard et al., 2000): the data covers the period 1986 to 1996, and is at a scale of 1:100,000 - the scale of the Landsat TM data which has a spatial resolution of 30mx30m. There is a 25 ha minimum mapping unit, and the grid pixel size of the dataset is 100m by 100m. It is also available in a 250mx250m grid pixel size which has been aggregated from the 1: 100,000 scale vector data.

The 25 ha minimum mapping size of the Corine data provides an area which is homogeneous, and whose combination of elementary areas, represents characteristic land cover structures, while the scale of 1:100,000 represents a significant area of land. The Corine project while using satellite data which is at a finer resolution, has mapped these to the larger 25ha unit in classifying the data.

However, a scale of 1:100,000 is better suited to identification of national level trends, while 1: 25,000 is suited to regional land use trends. The difference in scale is illustrated in Figure 6.1. This finer scaled 1: 25,000 classification has been produced by the Murbandy/Moland project which has a minimum map area of 1 ha or 100mx100m for artificial surfaces, and 3 ha or 170mx170m for non-artificial surfaces. This database covers the years 1997-1998 and is based on high resolution satellite imagery (IRS1-C panchromatic) at a 5.7 m spatial resolution. In addition, the Murbandy/Moland data is of land use while Corine is of land cover. It uses the Corine land cover nomenclature, but extends this to the artificial surfaces and water bodies to provide a higher level of socio economic information. While it is recognized that this finer scale is more appropriate to a regional study of urban sprawl, the Corine data is more readily available. Future work will examine the use of landscape ecology metrics using comparing the Corine dataset with the Murbandy/Moland data.



The top row illustrates the map scale, while the bottom row illustrates the level of detail of the classified remotely sensed data

Figure 6.1: Scale of Corine and Murbandy/Moland data (EEA-DG-JRC, 2002)

The Corine data has been reclassified to three land use classes Urban Residential, Urban Commerical/Industrial and Non-Urban, using the ArcGIS software. The recombination is shown in Table 6.3. The table shows the original levels of classification: level one, level two and level three, with level one the most generalized and level three the least. These have been reclassified into the categories of urban residential, urban commercial / industrial and non – urban as shown in Table 6.3.

Table 6.3: Reclassification of the Corine data

Code	Level1	Level2	Level3	Study Area Class
1	Artificial surfaces	Urban fabric	Continuous urban fabric	1 Urban Residential
2	Artificial surfaces	Urban fabric	Discontinuous urban fabric	1 Urban Residential
3	Artificial surfaces	Industrial, commercial and transport units	Industrial or commercial units	2 Urban Commerical/Industrial
4	Artificial surfaces	Industrial, commercial and transport units	Road and rail networks and associated land	2 Urban Commerical/Industrial
5	Artificial surfaces	Industrial, commercial and transport units	Port areas	2 Urban Commerical/Industrial
6	Artificial surfaces	Industrial, commercial and transport units	Airports	2 Urban Commerical/Industrial
7	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites	2 Urban Commerical/Industrial
8	Artificial surfaces	Mine, dump and construction sites	Dump sites	2 Urban Commerical/Industrial
9	Artificial surfaces	Mine, dump and construction sites	Construction sites	2 Urban Commerical/Industrial
10	Artificial surfaces	Artificial, non-agricultural vegetated areas	Green urban areas	1 Urban Residential
11	Artificial surfaces	Artificial, non-agricultural vegetated areas	Sport and leisure facilities	1 Urban Residential
12	Agricultural areas	Arable land	Non-irrigated arable land	3 Non -Urban
13	Agricultural areas	Arable land	Permanently irrigated land	3 Non -Urban
14	Agricultural areas	Arable land	Rice fields	3 Non -Urban
15	Agricultural areas	Permanent crops	Vineyards	3 Non -Urban
16	Agricultural areas	Permanent crops	Fruit trees and berry plantations	3 Non -Urban
17	Agricultural areas	Permanent crops	Olive groves	3 Non -Urban
18	Agricultural areas	Pastures	Pastures	3 Non -Urban
19	Agricultural areas	Heterogeneous agricultural areas	Annual crops associated with permanent crops	3 Non -Urban
20	Agricultural areas	Heterogeneous agricultural areas	Complex cultivation patterns	3 Non -Urban
21	Agricultural areas	Heterogeneous agricultural areas	Land principally occupied by agriculture, with significant areas of	3 Non -Urban
22	Agricultural areas	Heterogeneous agricultural areas	Agro-forestry areas	3 Non -Urban
23	Forest and semi natural areas	Forests	Broad-leaved forest	3 Non -Urban
24	Forest and semi natural areas	Forests	Coniferous forest	3 Non -Urban
25	Forest and semi natural areas	Forests	Mixed forest	3 Non -Urban
26	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Natural grasslands	3 Non -Urban
27	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Moors and heathland	3 Non -Urban
28	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Sclerophyllous vegetation	3 Non -Urban

Table 6.3 (continued)

Code	Level1	Level2	Level3	Study Area Class
29	Forest and semi natural areas	Scrub and/or herbaceous vegetation associations	Transitional woodland-shrub	3 Non -Urban
30	Forest and semi natural areas	Open spaces with little or no vegetation	Beaches, dunes, sands	3 Non -Urban
31	Forest and semi natural areas	Open spaces with little or no vegetation	Bare rocks	3 Non -Urban
32	Forest and semi natural areas	Open spaces with little or no vegetation	Sparsely vegetated areas	3 Non -Urban
33	Forest and semi natural areas	Open spaces with little or no vegetation	Burnt areas	3 Non -Urban
34	Forest and semi natural areas	Open spaces with little or no vegetation	Glaciers and perpetual snow	3 Non -Urban
35	Wetlands	Inland wetlands	Inland marshes	3 Non -Urban
36	Wetlands	Inland wetlands	Peat bogs	3 Non -Urban
37	Wetlands	Maritime wetlands	Salt marshes	3 Non -Urban
38	Wetlands	Maritime wetlands	Salines	3 Non -Urban
39	Wetlands	Maritime wetlands	Intertidal flats	3 Non -Urban
40	Water bodies	Inland waters	Water courses	3 Non -Urban
41	Water bodies	Inland waters	Water bodies	3 Non -Urban
42	Water bodies	Marine waters	Coastal lagoons	3 Non -Urban
43	Water bodies	Marine waters	Estuaries	3 Non -Urban
44	Water bodies	Marine waters	Sea and ocean	3 Non -Urban
49	NODATA	NODATA	NODATA	3 Non -Urban
50	Sea and ocean	Sea and ocean	Sea and ocean	3 Non -Urban

The data was amalgamated to grids of 100mx100m, 300mx300m, and 500mx500m with the metrics calculated at each resolution. The measures were calculated at three resolutions as the spatial resolution of the data impacts on the results (McGarigal and Marks, 1995). This is a new element of the thesis as previous studies have not examined the impact of varying resolution on the measures for identification of urban sprawl. At coarser scales, fewer patches emerge as it is clear when we compare, for instance, the 3 patches of non urban in the 100 m scale to the 2 patches in the 300 m scale. This difference in grid size is likely to be an issue for metrics measuring edge length resulting in an upward bias with increased cell sizes due to the stair step outline. Metrics based on cell adjacency such as contagion indices are affected as grain size affects the proportional distribution of adjacencies with larger grain sizes having less adjacencies proportionally.

Figure 6.2 shows the differences in resolution for the City of Bath .

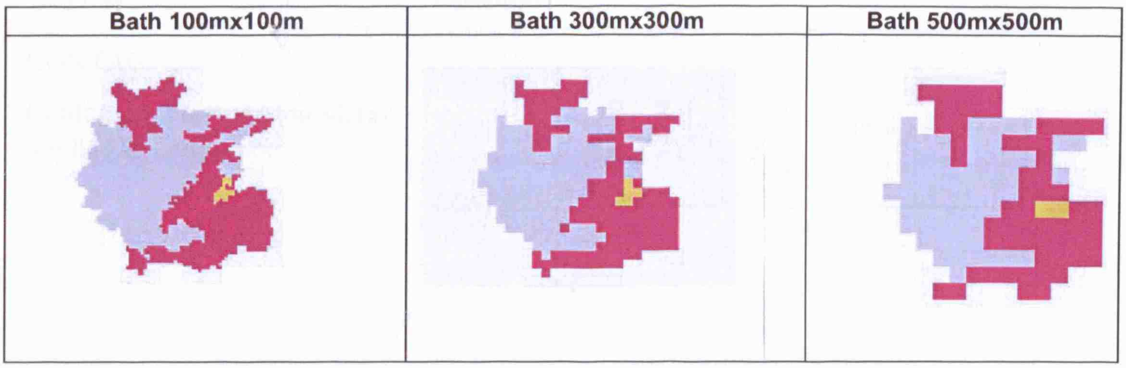


Figure 6.2 : Reclassified study area at varying spatial resolutions (from Corine 1990 100m resolution)

It should be noted that the region, which is the former County of Avon has been divided into the 1998 unitary authorities of Bristol, South Gloucestershire, Bath and NorthEast Somerset, North Somerset, and the 1991 districts of Bristol, Bath, Kingswood, Wansdyke, North Avon, Woodspring. The area of Avon was 1347km^2 (520mi^2) and its population in 1991 was 919,800.

The metrics used are calculated in the software package Fragstats v3, developed by McGarigall and Marks at the University of Massachusetts originally published in 1995 (McGarigal and Marks, 1995). The metrics and their interpretation are described in Table 6.4.

Table 6.4: Landscape ecology measures used to identify urban sprawl in Bristol

Measure	Equation
CONTAG Contagion Interspersion Metric applied to Landscape	$$CONTAG = \left[1 + \frac{\sum_{i=1}^{m} \sum_{k=1}^{m} \left[p_i \left[\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right] \right] + \ln(p_i) \left[\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}} \right]}{2\ln(m)} \right] (100)$$ p_i =proportion of the landscape occupied by patch type (class) g_{ik} =number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* method m =number of patch types (classes) present in the landscape, including the landscape border if present
IJI Interspersion and Juxtaposition Index applied to Landscape	$$IJI = \frac{\sum_{i=1}^{m} \sum_{k=i+1}^{m} \left[\frac{e_{ik}}{E} \right] + \ln \left[\frac{e_{ik}}{E} \right]}{\ln(0.5[m(m-1)])} (100)$$ e_{ik} =total length (m) of edge in landscape between patch types (classes) i and k. E =total length (m) of edge in landscape, excluding background. m =number of patch types (classes) present in the landscape, including the landscape border, if present.
PD Patch Density applied to class	$$PD = \frac{n_i}{A}(100)$$ n_i =number of patches in the landscape of patch type (class) i. A =total landscape area (m^2).

Table 6.4 (continued)

Measure	Equation
Area_SD Patch Area Standard Deviation applied to class	$SD = \sqrt{\frac{\sum_{j=1}^{m} x_{ij} - \left[\frac{\sum_{j=1}^{m} x_{ij}}{n_i}\right]}{n_i}}$ n_i =number of patches in the landscape of patch type (class) j x_{ij} is the area of each individual patch
ED Edge Density applied to class	$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}$ e_{ik}=total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving patch type i. A =total landscape area (m^2).
FRAC_AM Area Weighted Mean Patch Fractal Dimension or Shape Fractal Dimension Index, applied to class	$FRAC = \frac{2\ln(.25 p_{ij})}{\ln a_{ij}}$ p_{ij} = perimeter (m) of patch ij. a_{ij} = area (m^2) of patch ij.
LPI Largest Patch Index applied to class	$LPI = \frac{\max_{j=1}^{a}(a_{ij})}{A}(100)$ a_{ij} = area (m^2) of patch ij. A =total landscape area (m^2).
ENN_ MNN Euclidean mean nearest neighbour distance applied to class	$ENN = h_{ij}$ h_{ij} =distance (m) from patch ij to nearest neighbouring patch of the same type (class), based on patch edge-to-edge distance, computed from cell centre to cell centre.

The contagion metric (CONTAG) varies between 0 and 100. It approaches zero when the land use types are maximally disaggregated (that is, when every cell is a different land use type) and interspersed (there are equal proportions of all pair-wise adjacencies). The metric has a value of 100 when all land use types are maximally aggregated (that is when the landscape consists of a single land use).

Contagion measures the extent to which landscapes are aggregated or clumped. Landscapes with patches of large but fragmented cover have a low contagion index. Urban areas which are large and compact have a high index. The contagion measure reflects only the intermixing of patches, and is not affected by size of patch. This index is strongly affected by resolution of the image. In terms of urban sprawl, a scattered or fragmented landscape would be expected to have a low value on the contagion measure.

The interspersion and juxtaposition index (IJI) varies between 0 and 100. IJI approaches zero when the distribution of adjacencies among land use patches becomes increasingly uneven. IJI is equal to 100 when all patches of a particular land use are equally adjacent to all other land use patches (i.e. maximum interspersion and juxtaposition). IJI is based on patch adjacencies, not cell adjacencies like the contagion index. Landscapes with four large patches and four land use types results in the same IJI as one with 100 small patches and four land use types if both are equally interspersed. In terms of sprawl, IJI can be used as an indicator of mixed use development, where urban areas with a higher level of interspersion are considered to be mixed use. It is less useful for identifying leap-frog or scattered development as the number and size of patches is not accounted for in this measure.

Patch density (PD) is ultimately constrained by the grain size of the raster image, as the maximum PD is attained when every cell is a separate patch. Therefore, ultimately cell size will determine the maximum number of patches per unit area. Landscapes with a finer resolution result in greater density of patches, and spatial heterogeneity occurs at finer resolutions. This provides some indication of the density of a particular land use type but as patch size is not taken into account, does not measure the extent of scattered or leapfrog development. Patch area standard deviation (SD) indicates the distribution of patch sizes in the landscape and is calculated as the square root of the sum of the squared deviations of each patch metric value from the mean metric value of the corresponding land use type, divided by the number of patches of the same land use. Note that this is the population standard deviation, not the sample standard deviation. Edge density (ED) measures the total length of the edge of the urban patches. The amount of edge present can be compared to that expected for a maximally compact class of the same size but with a simple geometric shape. The higher the edge density the greater the fragmentation of the landscape and the less compact the development. The measure is equal to zero when there is no edge in the landscape for a particular land use type – this occurs when the entire landscape consists of a particular land use. It can be used to indicate the extent of scattered development or fragmentation of the landscape.

Mean patch fratal dimension (FRAC_AM) describes the complexity and the fragmentation of a patch by a perimeter – area proportion. Fractal dimension ranges between 1 and 2 with low values derived when a patch has a compact rectangular form. If patches are complex and fragmented, the dimension increases. Higher fragmentation indicates greater levels of sprawl. Largest Patch Index (LPI) describes the percentage of total urban land represented by the largest urban patch. It is equal to the area of the largest patch of the corresponding patch type divided by total landscape area, multiplied by 100. LPI approaches zero when the largest patch of the corresponding patch type is increasingly small. LPI is equal to 100 when the entire landscape consists of a single patch of the corresponding land use type; that is, when the largest patch comprises 100 percent of the landscape. This provides some indication of homogeneity of land use

Mean Nearest Neighbour (ENN) measures the average minimum distance between the individual urban patches and indicates the extent of patch isolation within the residential land use class. It is equal to the distance to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance. Note that the edge-to-edge distances are from cell centre to cell centre. ENN approaches zero as the distance to the nearest neighbour decreases. The metric provides some indication of the spread of development throughout the landscape.

6.12 Summary

The study examines three variants on the measures of sprawl, aggregate density measures, measures identifying spatial pattern of sprawl based on residential and employment data, and measures identifying patterns of sprawl based on remotely sensed land cover data. It examines the applicability of the measures at four areas of geographical extent, two administrative areas(the county and district) and two functional areas (the urban area and the travel to work area). The study compares these measures with the understanding of urban sprawl in Bristol, as defined by the measures used in the SCATTER project.

Measures based on density are frequently used to characterize urban sprawl, this section examines a series of aggregate measures, together with simple measures which attempt to identify differences in the urban area. The second set of measures examines patterns of urban sprawl using measures derived from residential segregation which examine local patterns within the urban area. The third set of measures examines urban sprawl as characterized by land cover data, using measures derived from landscape ecology. The sections illustrate developments in the measures of sprawl from popular but aggregate measures which do not reflect differences in the urban area. This failing is addressed by measures which allow for examination of local patterns, and differences across the urban area. However, these measures do not allow for separation of land uses which can include large rural areas which affect the identification of sprawl. This is tackled by measures based on land use patterns which are examined using measures derived from landscape ecology. The study will examine the extent to which sprawl is a phenomenon that can be measured consistently focusing particularly on the idea that the spatial scale at which urban sprawl is observed can heavily influence the identification of relevant issues and the selection and design of suitable indicators. The next chapter will present the results of applying these measures to the identification and analysis of urban sprawl.

Chapter 7

Interpretation of Measures

7.1 Introduction

This chapter will present the results of measures of urban sprawl outlined in chapter six. It compares the results of these measures at four spatial scales examining the ability to identify sprawl within polycentric urban areas, with particular reference to the results for the Bristol region. This extends the measures identified by the SCATTER project, discussed in chapters four and five, allowing for further exploration of urban sprawl in the European context, particularly with reference to the identification of sprawl at European city scales and densities.

Throughout this section the maps presenting the results of the measures use the county boundaries for the mapping unit, regardless of the spatial scale of the measure. This allows for comparison across scales and aids the identification of the areas.

7.2 Measures Based on Density

The measures are outlined in Table 6.1 of chapter six and are calculated for 44 of the counties of England, and corresponding urban areas, travel to work areas and districts (except for Inner and Outer London) as outlined in section 6.6. Appendix A presents the areas for which measures were calculated, the four scales (county, district, urban and travel to work) for each area, and the code associated with each area for the 1991 Census. The average density based on the population weighted density (pwd) measure ranges from 16 to 22 persons per hectare (1600 to 2200 persons per km^2), a moderate suburban density, with a fairly consistent performance across spatial scales, as shown in Table 7.1 and Figure 7.1 and

Figure 7.2.

Looking in more detail at the variation among the 44 areas, the district and urban spatial scales result in much higher densities than the county and travel to work areas. For instance, in Bristol, this reflects the uniform development of the urban and district scale at high densities, compared to the presence of rural and lower density areas within the county and travel to work areas. In these cases the measure is sensitive to spatial scale and does not accurately identify urban sprawl.

Table 7.1: Summary statistics population weighted density (per ha)

PWD	Minimum	Maximum	Mean	Std Deviation	Skewness	Kurtosis
County	10.80	25.50	16.70	3.41	0.72	0.38
District	11.40	64.25	21.23	9.35	2.40	10.18
Urban	10.07	62.68	21.61	9.41	2.23	8.73
TTW	11.46	51.68	18.78	8.02	2.26	8.29

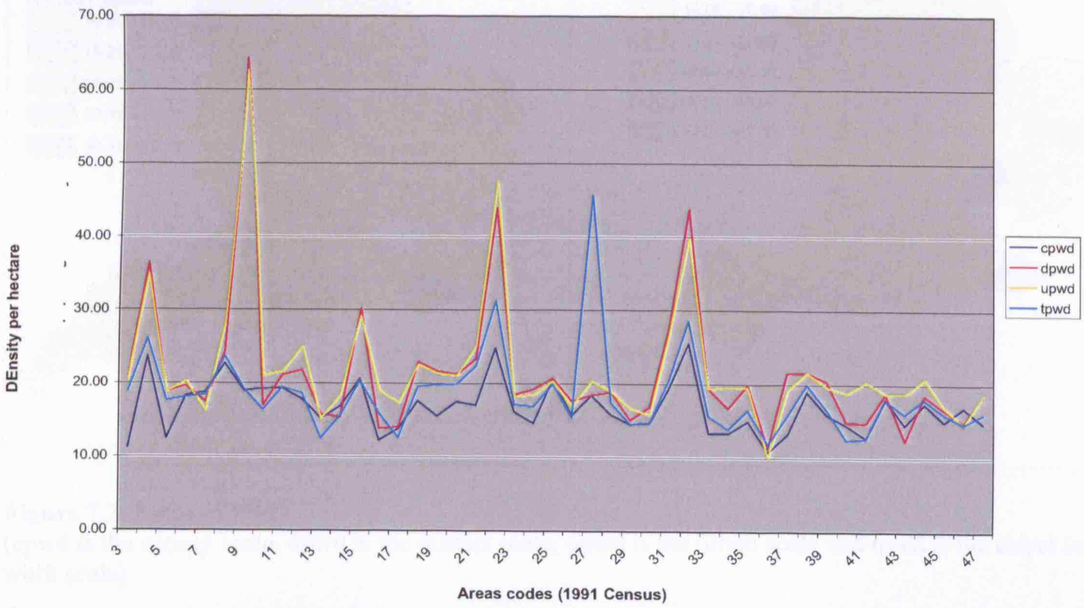


Figure 7.1: PWD across spatial scales

(cpwd is the county scale, dpwd is the district scale, upwd is the urban scale and tpwd is the travel to work scale).

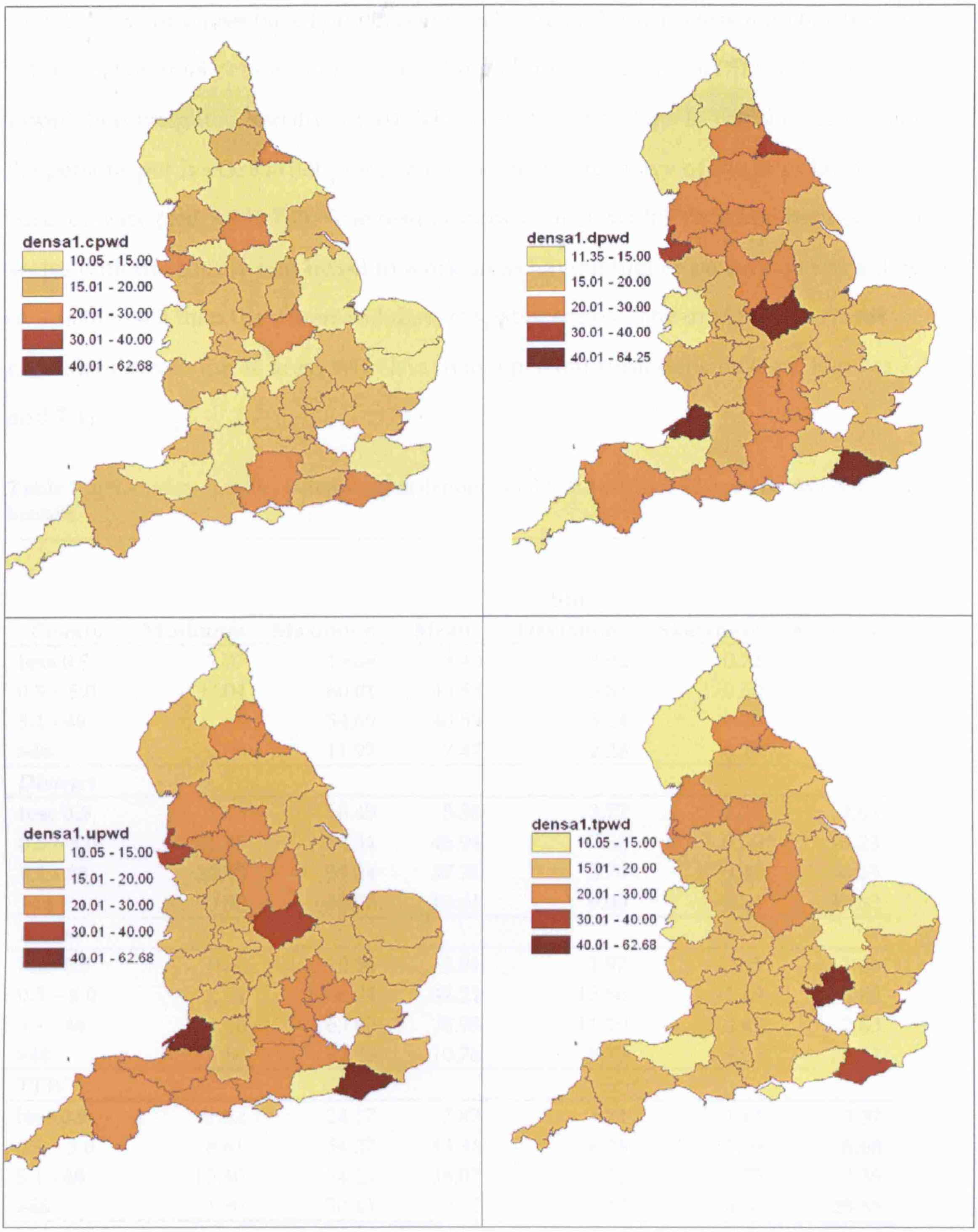


Figure 7.2: Maps of PWD
(cpwd is the county scale, dpwd is the district scale, upwd is the urban scale and tpwd is the travel to work scale)

The density measures based on percentages living at densities less than 0.5, 0.51-5.0, 5.1-48 and over 48 persons per hectare show more variation than the aggregate population weighted density (pwd). The average percentage living at densities below 0.5 persons per hectare is 3.9 - 7.9 percent, a small percentage of the population, at this rural density (see Table 7.2). The results show a much wider variation between spatial scales with the county and travel to work areas having higher percentages at a density of less than 0.5 than the urban and district spatial scales. The urban area is most consistent across the 44 areas with less than 5 percent rural densities (see Figures 7.3 and 7.4)

Table 7.2: Summary statistics percentages at densities of 0.5, 0.5-5.0, 5.1-48 and over 48 persons per hectare

County	Minimum	Maximum	Mean	Std Deviation	Skewness	Kurtosis
less 0.5	1.07	19.68	8.40	4.92	0.71	-0.51
0.5 – 5.0	32.04	60.01	43.53	5.81	0.60	0.70
5.1 - 48	31.89	54.69	40.59	5.24	0.46	-0.03
>48	4.05	11.97	7.47	2.28	0.23	-0.94
District						
less 0.5	1.85	16.48	5.38	3.77	1.78	2.65
0.5 – 5.0	31.45	64.44	46.94	7.85	0.00	-0.23
5.1 - 48	20.45	59.24	37.76	8.74	0.41	-0.15
>48	3.90	65.00	10.61	9.00	5.14	30.83
Urban						
less 0.5	0.00	10.16	3.91	1.97	0.51	1.66
0.5 – 5.0	2.81	66.84	44.21	12.86	-1.49	3.88
5.1 - 48	21.26	63.40	38.93	11.10	-0.47	2.63
>48	1.66	61.83	10.76	8.73	4.61	26.72
TTW						
less 0.5	1.62	24.17	7.87	4.71	1.65	3.37
0.5 – 5.0	8.61	54.27	43.31	8.08	-1.98	6.68
5.1 - 48	15.40	54.23	38.07	6.52	-0.75	3.35
>48	1.90	50.43	9.22	7.17	4.56	25.55

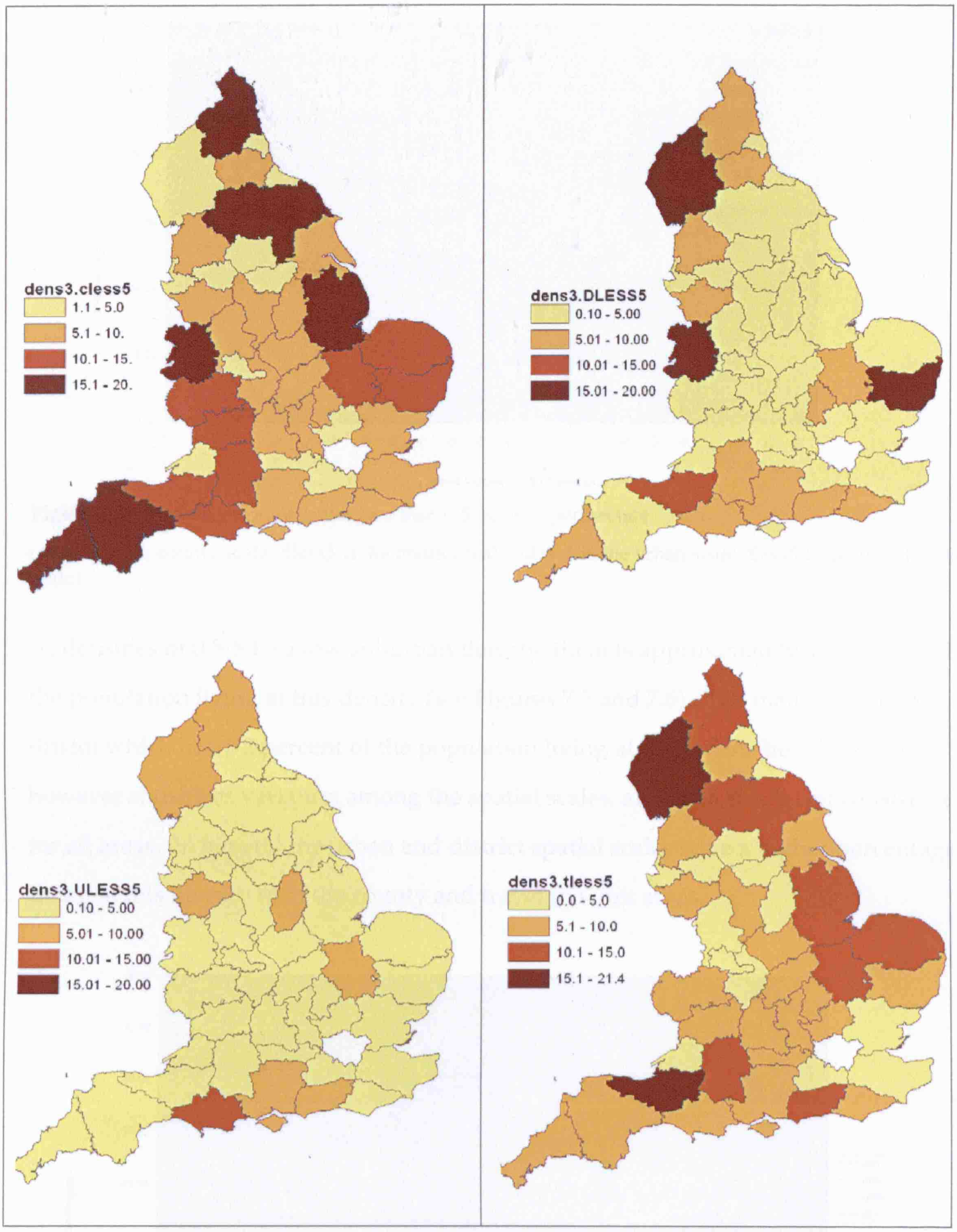


Figure 7.3: Map of areas at less than 0.5 persons per hectare

(cless5 is the county scale, dless5 is the district scale, uless5 is the urban scale and tless5 is the travel to work scale)

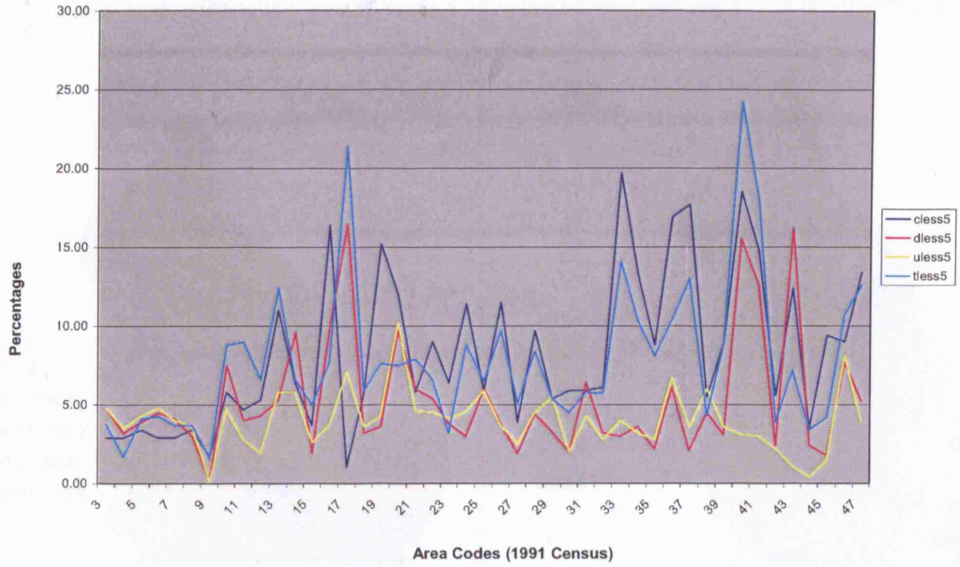


Figure 7.4: Percentages at densities less than 0.5 persons per hectare

(cless 5 is the county scale, dless5 is the district scale, uless5 is the urban scale, tless5 is the travel to work scale)

At densities of 0.5-5.1 - a low suburban density, there is approximately 43-46 percent of the population living at this density (see Figures 7.5 and 7.6). The main exception is Bristol which has 1-2 percent of the population living at these densities. The results however show less variation among the spatial scales, although this is not consistent for all areas. In general the urban and district spatial scales have a higher percentage living at this density than the county and travel to work areas.

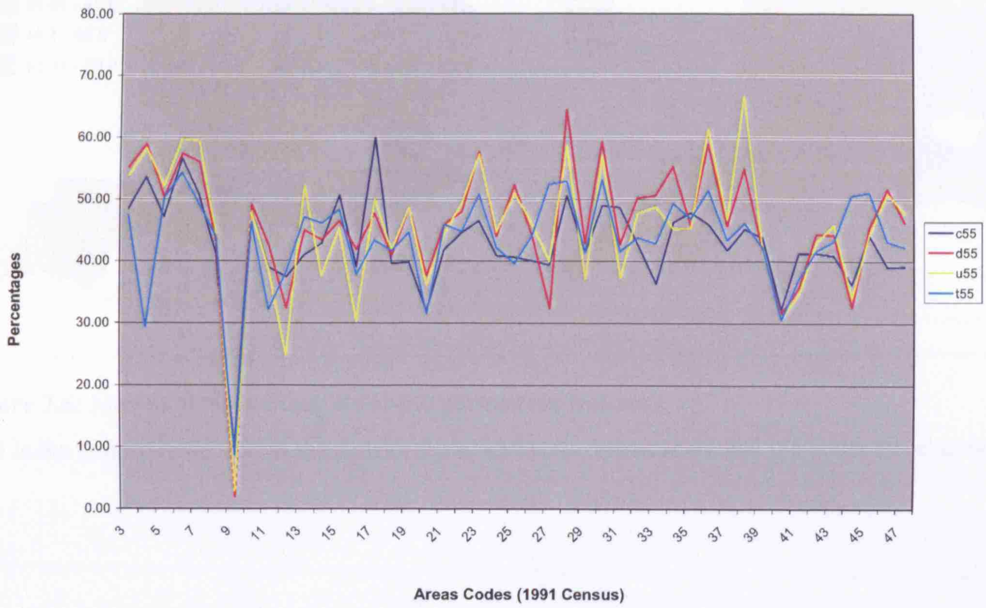


Figure 7.5: Percentages living at densities between 0.51-5.0 persons per hectare

(c55 is the county scale, d55 is the district scale, u55 is the urban scale and t55 is the travel to work scale)

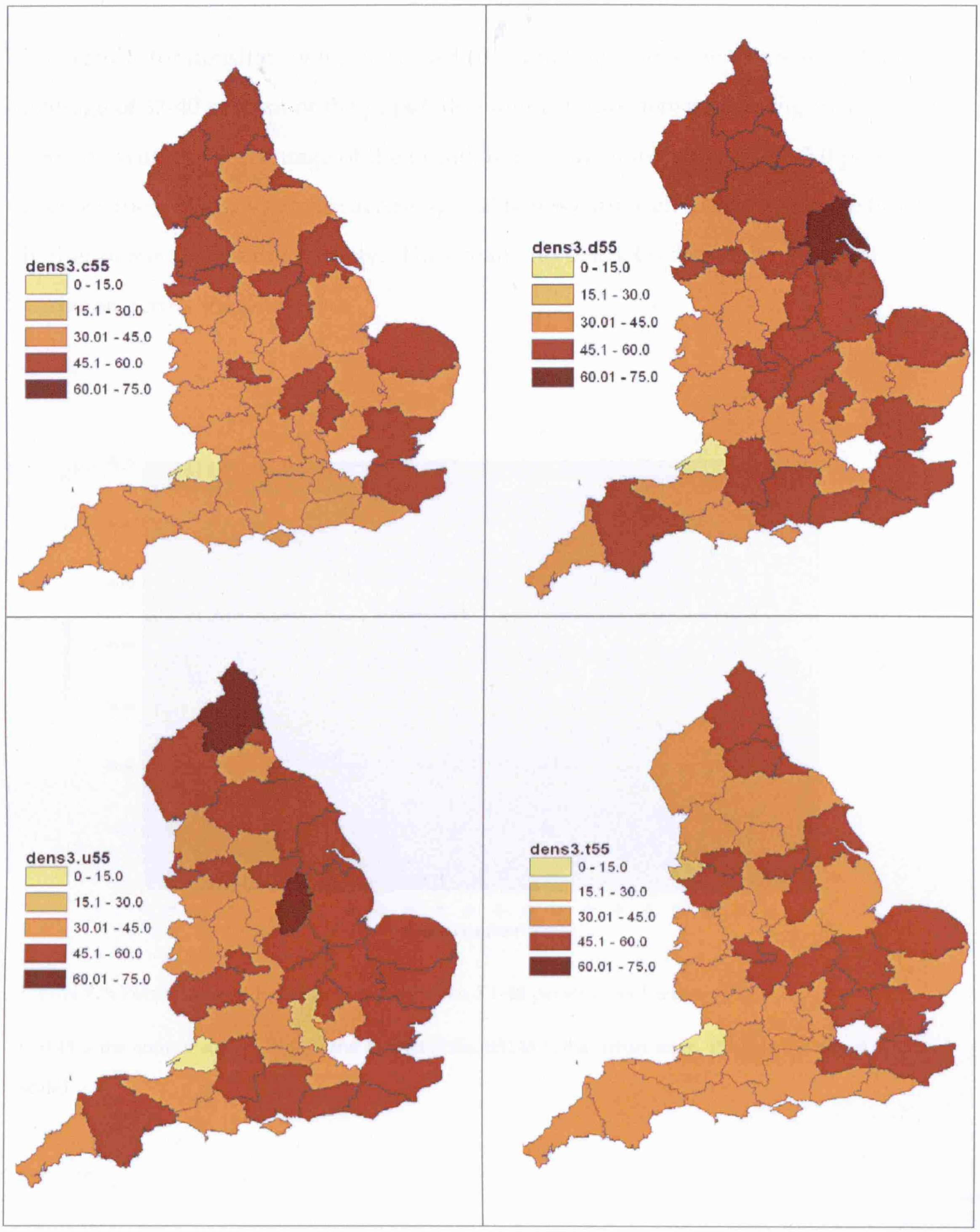


Figure 7.6: Map of persons living at 5.1-5.0 persons per hectare

(c55 is the county scale, d55 is the district scale, u55 is the urban scale and t55 is the travel to work scale)

The results for densities of 5.1-48 show little variation across the 44 areas with an average of 37-40 percent of the population living at this density (see Figures 7.7 and 7.8). As with the percentage of the population living at densities of 0.5-5.0 persons per hectare, there is less variation across spatial scales, although the county scale has a higher percentage at this density. The urban and district scales show the most variation across the 44 areas.

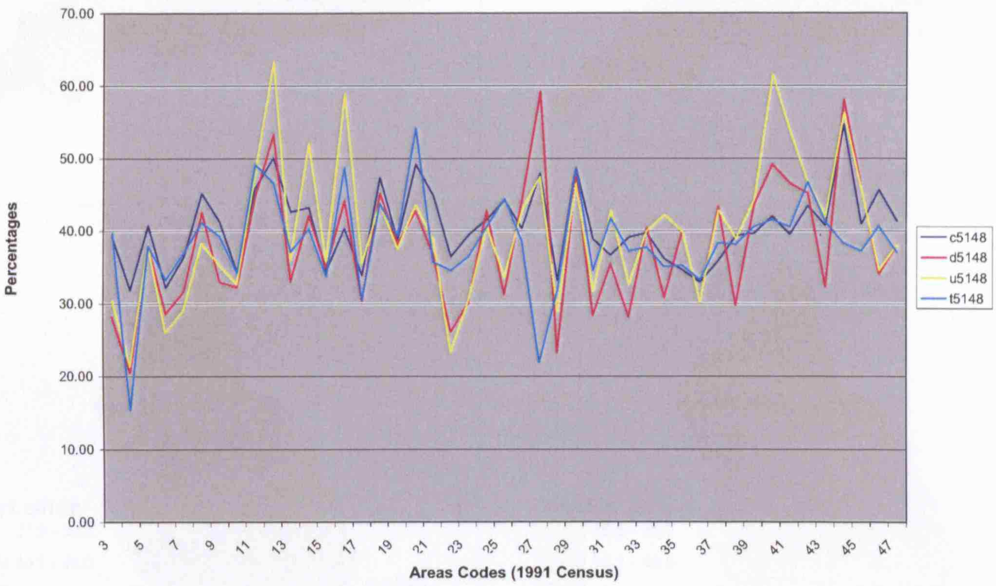


Figure 7.7: Percentages living at densities between 5.1-48 persons per hectare

(c5148 is the county scale, d5148 is the district scale, u5148 is the urban scale, t5148 is the travel to work scale)

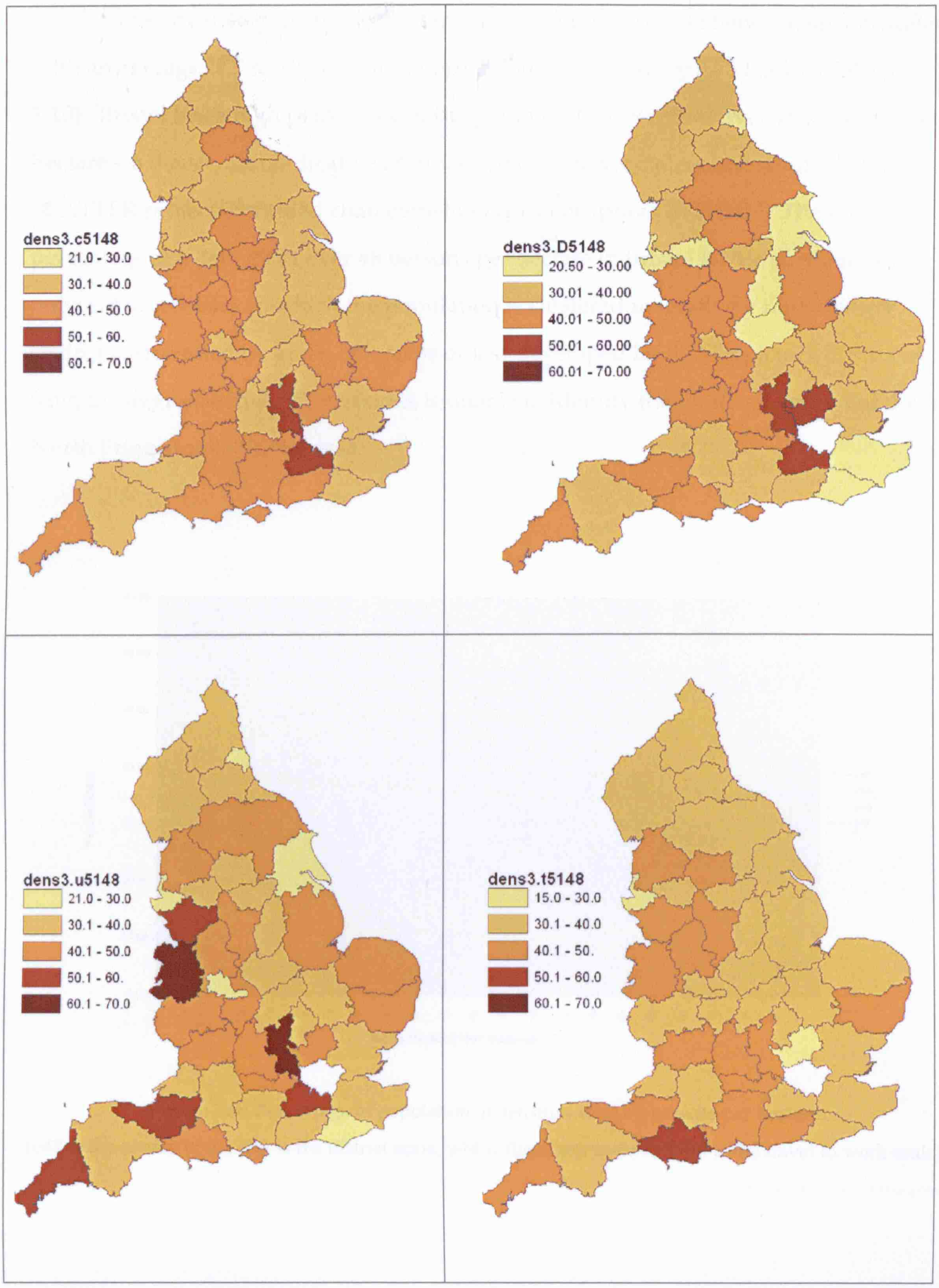


Figure 7.8: Maps of persons at 5.1-48 persons per hectare

(c5148 is the county scale, d5148 is the district scale, u5148 is the district scale and t5148 is the travel to work scale)

For densities over 48 persons per hectare, there is little variation between spatial scales with an average of 7 to 10 percent of population at this density (see Figures 7.9 and 7.10). Bristol has a high percentage of the population at densities over 48 persons per hectare – a density not indicative of urban sprawl. Nevertheless, the results of the SCATTER project identified characteristics typical of sprawl in Bristol. The high percentage at a density of over 48 persons per hectare in Bristol is due partly to the polycentric network in which the population is clustered in relatively high density centres surrounded by green belt areas or less developed land. The picture of sprawl from the aggregate density measures is unable to identify the localized sprawl of the North Fringe in the Bristol case.

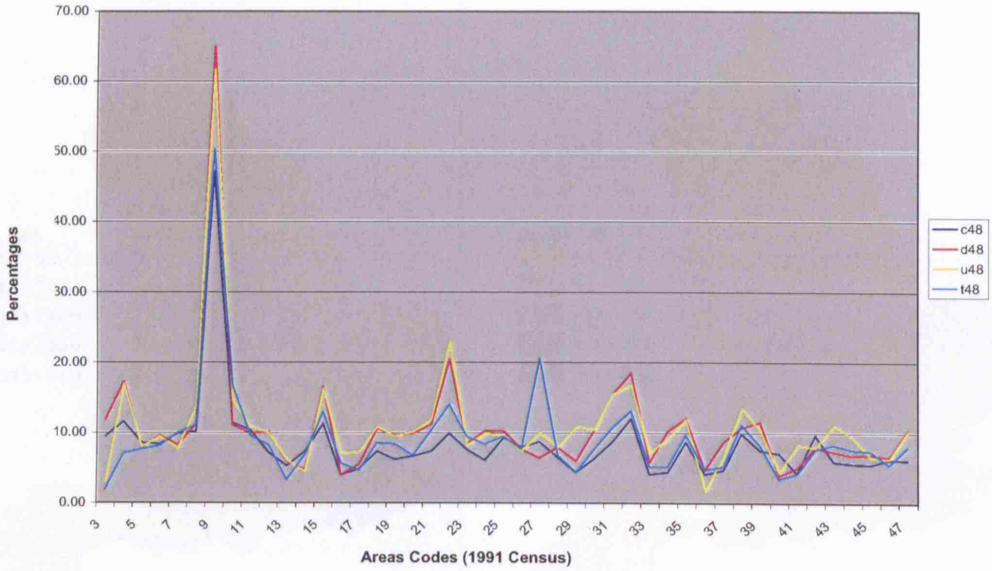


Figure 7.9: Percentage of population at densities over 48 persons per hectare (c48 is the county scale, d48 is the district scale, u48 is the urban scale and t48 is the travel to work scale)

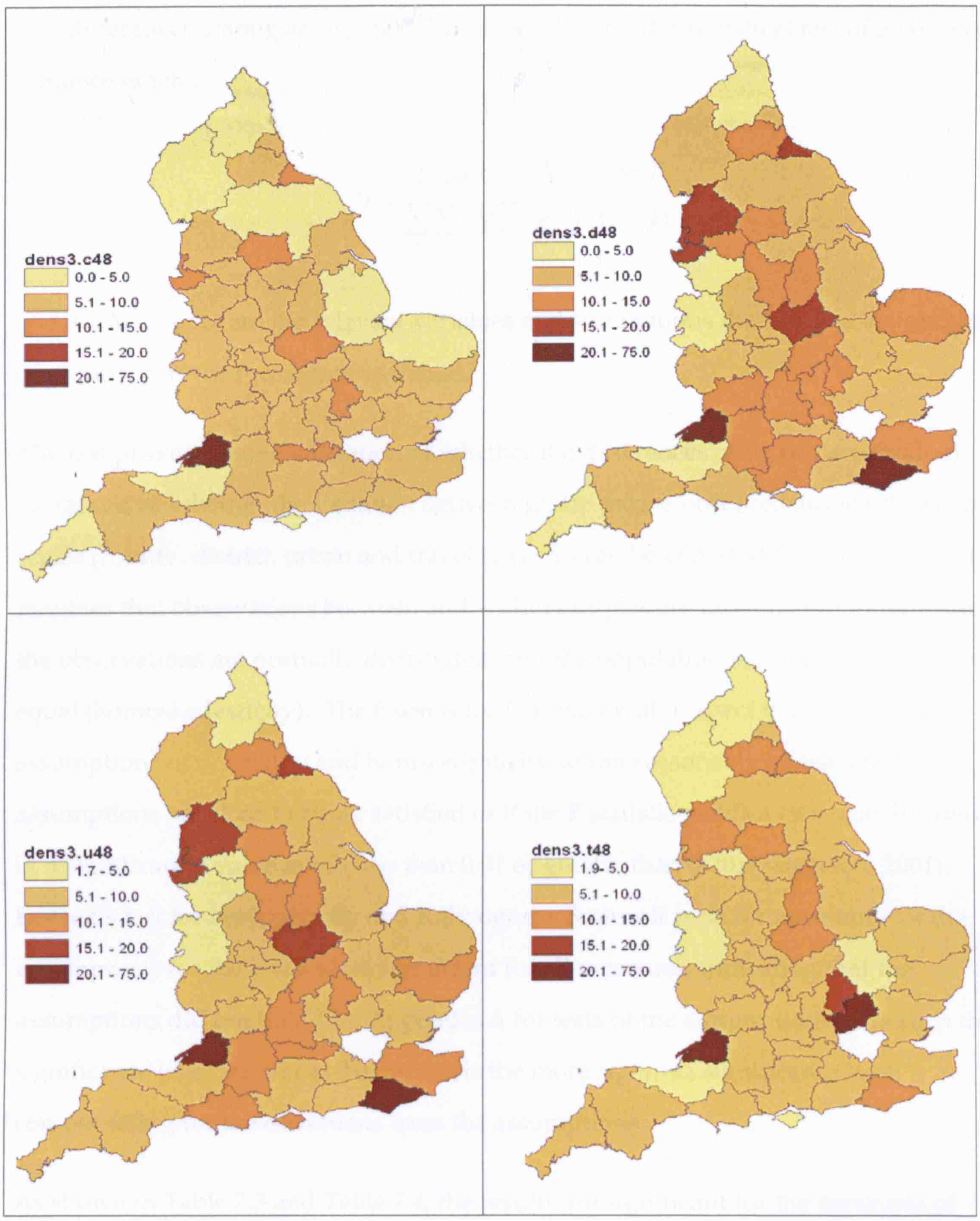


Figure 7.10: Map of percentages over 48 persons per hectare
(c48 is the county scale, d48 is the district scale, u48 is the urban scale and t48 is the travel to work scale)

The differences among areas were also assessed using the statistical test of analysis of variance where:

$$F = \frac{\sum_{j}^{i} n_j (X_{+j} - X_{++})^2 / (k-1)}{\sum_{i}\sum_{j} (X_{ij} - X_{+j})^2 / (N-k)}$$

and X_{+j}, X_{++}, X_{ij}, X_{+j} are the relevant variables and summations thereof, k is the number of groups, N is the number of variables.

The test provides some indication of whether the differences observed are random variations or whether the variation between group means observed among the spatial scales (county, district, urban and travel to work) can be expected to occur. The test assumes that observations between and within samples are random and independent, the observations are normally distributed, and the population variances are assumed equal (homoskedasticity). The F test is fairly robust with respect to deviations from the assumptions of normality and homscedasticity so can reasonably be used if the assumptions are close to being satisfied or if the F statistic yields a clear conclusion(that is, a significant p value much less than 0.01 or greater than 0.20) (Rogerson, 2001). Levene's test for homogeneity and Kolmogorov Smirnoff tests for normality of the assumptions for the F test were significant for all measures, indicating that the assumptions did not hold (see Appendix A for tests of the assumptions). As such the significance level was set at 0.01 which is the more rigorous significance level compensating for the deviations from the assumptions.

As shown in Table 7.3 and Table 7.4, the results are significant for the measures of population weighted density, percentage of the population at less than 0.5 persons per hectare, and just above significance for percentage above 45 persons per hectare. The differences observed among the spatial scales for these measures are more likely to be actual differences. Of the significant results, the urban and district scale have similar means, while the county and travel to work have similar means. As such the distinction between the administrative and the functional areas are less important than the spatial extent of the area used to examine urban sprawl.

Table 7.3: Results of the F test for measures of density

Measure	d.f		F	p value
PWD	Between	3	4.069	0.002
	Within	176		
	Total	179		
< 0.5	Between	3	12.210	0.000
	Within	176		
	Total	179		
0.5 - 5.0	Between	3	1.450	0.230
	Within	176		
	Total	179		
5.1 - 48	Between	3	0.873	0.456
	Within	176		
	Total	179		
>48	Between	3	3.703	0.013
	Within	176		
	Total	179		

Table 7.4: Post Hoc contrasts for the measures of density (significant results)

Measure	Area (I)	Area (J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
PWD	county	urban	1.224	0.004	-8.764	-0.392
< 0.5	county	district	0.854	0.007	0.610	5.432
< 0.5	county	urban	0.854	0.000	1.981	6.803
< 0.5	urban	ttw	0.859	0.000	-6.47	-1.597

The aggregate measures of density are subject to fluctuations depending on spatial scale, and particularly for low to moderate suburban densities, these do not provide much distinction among the 44 areas. Measures based on density, despite their popularity for identifying urban sprawl, are unable to identify the nature of sprawl in the European context. This is particularly the case where the urban form is polycentric, where as in the case of Bristol, existing patterns are composed of localised low density urban growth in a region with otherwise high density pockets of development.

Measures providing an examination of the central city with the surrounding area have been developed by several groups (Duncan and Duncan, 1955; Galster et al., 2001;

James and Taueber, 1985; Massey and Denton, 1988; Massey et al., 1996; Taeuber and Taeuber, 1965; Transportation Research Board, 2002). This set of measures looks at the population density outside the central city, the ratio of the central city's density to the urban area, and the percentage of the area living outside the central city. These measures can be seen as a simple measure of centralization which however does not take account of the actual distribution of the population in space. Given that this set of measures relies heavily on the definition and size of the central city, the measures have been calculated with employment centres defined at four densities. From the initial results of the case study of Bristol, the county area has been used as the spatial scale suitable for identifying polycentric subcentres, as the travel to work area excludes the centre of Bath, and the urban and district areas encompass only the Bristol urban area.

The measures examining variations in density around the central city and its subcentres identify the central city and the subcentres using the methods developed by Small and Song (1994) discussed in chapter six. The measures apply to the county area only and are created using subcentres based on varying employment densities per acre of 5, 7, 10 (1235, 1730, and 2470 per km^2) and the regional average (see Appendix A for the regional average employment densities used to define these employment subcentres for the areas). At certain densities, there were no subcentres identified and for the Isle of Wight 29 all densities were below the threshold

The measure of population density at the fringe (pdfr) is fairly stable across employment centre definitions, with little variation across study areas (see Table 7.5, and Figures 7.11 and 7.12), which have an average density of 357-415 persons per km^2. This contrasts with the average population weighted density for the county of 1670 km^2. Taking into account the polycentric nature of the urban areas through multiple sub centres results in lower densities and is more likely to identify areas as sprawling. The population density of Bristol is also lower than for the population weighted density as the population in the centres of Bristol, Bath and Weston-super-Mare is not included in the fringe but in the central cities.

Table 7.5: Summary statistics density measures of employment centres

	Minimum	Maximum	Mean	Std Deviation	Skewness	Kurtosis
pdfr05	58.66	1772.22	363.72	396.91	2.66	6.78
pdfr07	58.66	1932.30	393.26	434.58	2.70	7.04
pdfr10	58.66	2046.68	415.14	455.41	2.65	6.82
pdfro	50.21	2046.68	357.24	471.05	2.87	7.79
rpd05	2.01	49.87	13.34	9.34	1.77	4.72
rpd07	1.65	63.90	14.69	12.80	2.19	5.86
rpd10	1.41	50.17	12.48	10.46	1.96	4.50
rpdo	2.63	45.81	16.09	10.03	1.27	1.84
perpcc05	0.00	79.44	17.37	13.20	2.62	10.81
perpcc07	0.00	71.55	10.66	11.22	3.93	20.37
perpcc10	0.00	68.47	5.42	10.28	5.59	34.67
perpcco	0.00	53.73	28.19	12.01	-0.80	1.05

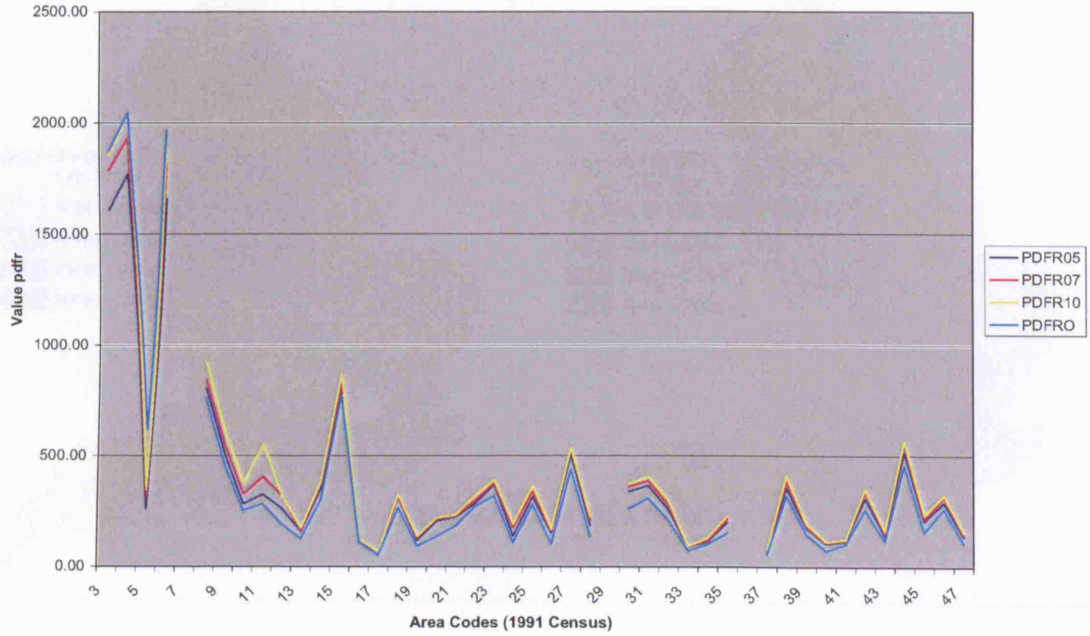


Figure 7.11: Population density outside of employment centres

(pdfr05 is employment density centres at 5 persons/acre, pdfr07 is employment density centres at 7 persons/acre, pdfr10 is employment density centres at 10 persons/acre and pdfro is employment densitycentres at the regional average)

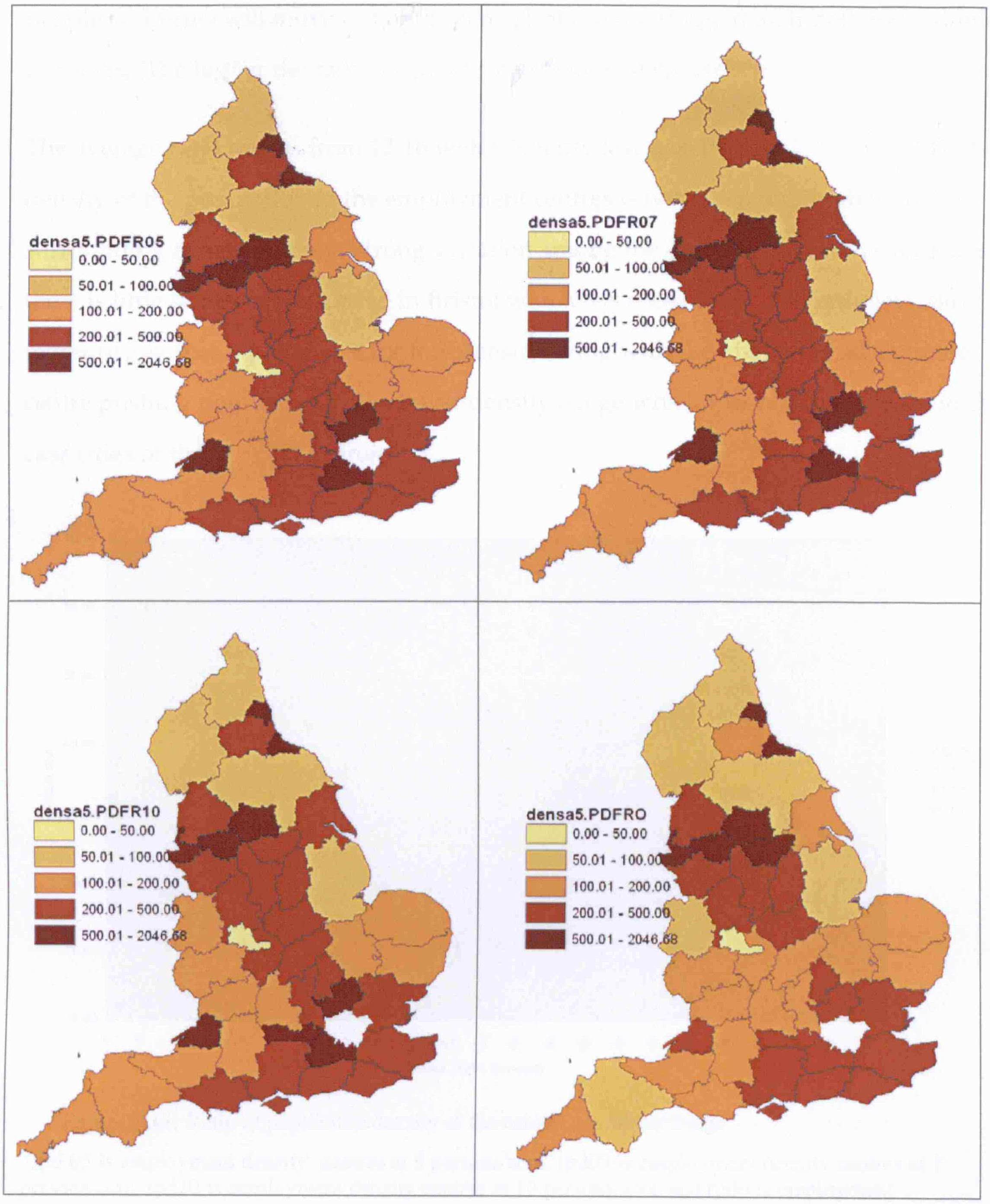


Figure 7.12: Map of population density outside employment centres

(pdfr05 is employment density centres at 5 persons/acre, pdfr07 is employment density centres at 7 persons/acre, pdfr10 is employment density centres at 10 persons/acre and pdfro is employment densitycentres at the regional average)

The ratio of central city's population density to the density of the urbanized fringe (rpd) provides evidence of urban sprawl if the central city has a much higher density than its surrounding urbanized fringe, assuming there is a greater likelihood that people and firms will move out of the central city to the fringe than if both have similar densities. The higher the ratio the greater the degree of sprawl.

The average ratio ranges from 12-16 which is fairly low (see Figures 7.13 and 7.14). The density of the population in the employment centres is not much higher than in the surrounding fringe. There is strong variation among the 44 areas but on this measure there is little potential for sprawl in Bristol which has a low ratio. Nevertheless, the measure assumes a preference for low density living with the higher densities in the centre pushing population to the lower density fringe which was not in evidence in the case cities of the SCATTER project.

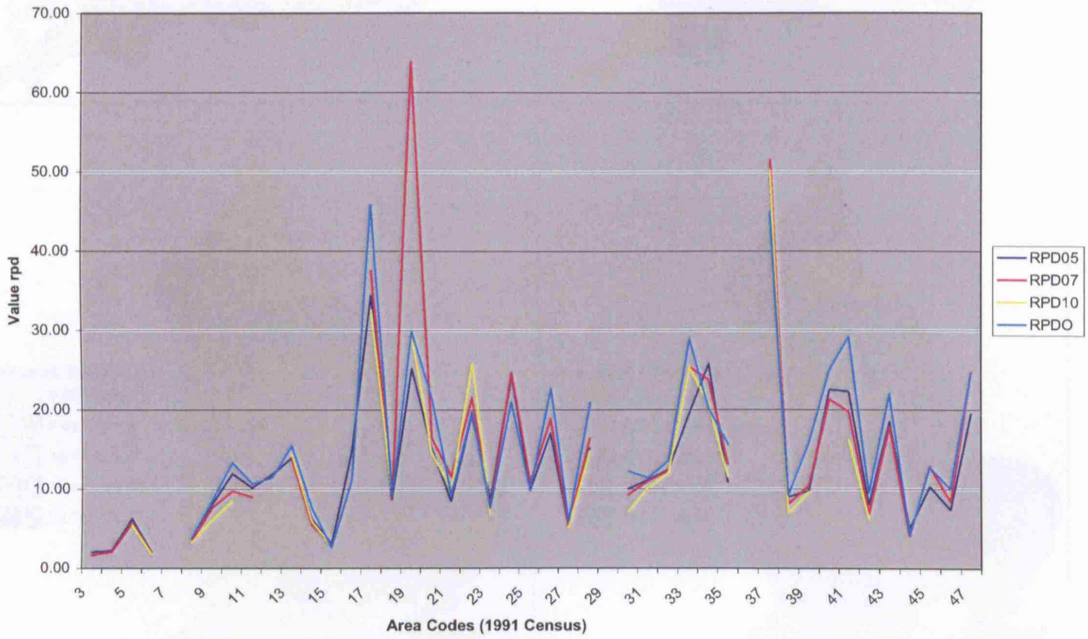


Figure 7.13: Ratio of population density of the central city to the fringe

(rpd 05 is employment density centres at 5 persons/acre, rpd07 is employment density centres at 7 persons/acre, rpd10 is employment density centres at 10 persons/acre and rpdo is employment densitycentres at the regional average)

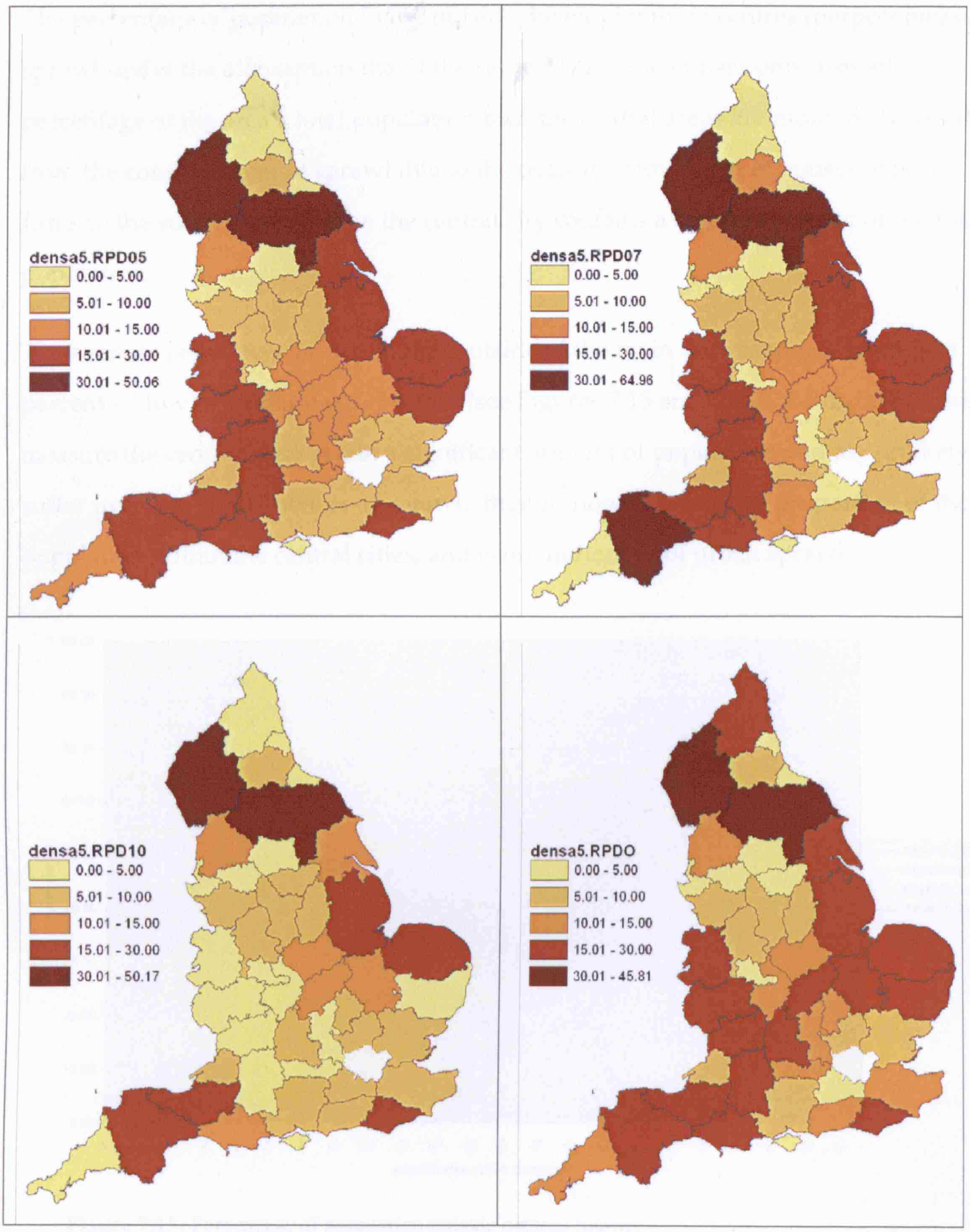


Figure 7.14: Maps of ratio of population density of the central city to the fringe

(rpd 05 is employment density centres at 5 persons/acre, rpd07 is employment density centres at 7 persons/acre, rpd10 is employment density centres at 10 persons/acre and rpdo is employment densitycentres at the regional average)

The percentage of population living outside the employment centres (perpcc) measures sprawl under the assumption that if the central cities encompass only a small percentage of the area's total population then the central areas are more likely to suffer from the consequences of sprawl due to the outward movement of households and firms to the suburbs than when the central city contains a high percentage of the total population.

The average percentage of population outside of the main centres ranges from 5-28 percent - a low to moderate proportion (see Figures 7.15 and 7.16). According to this measure the central areas retain a significant amount of population and are unlikely to suffer from the consequences of sprawl. Bristol shows a moderate proportion of the population within the central cities, and is not indicative of urban sprawl.

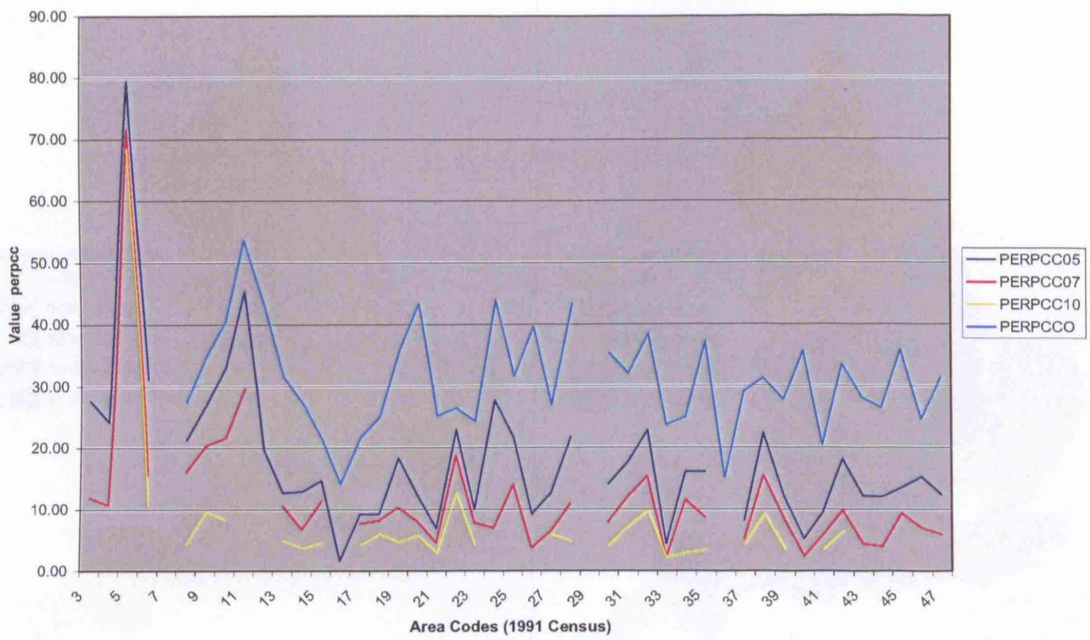


Figure 7.15: Percentage of population outside centres (perpcc)

(perpcc 05 is employment density centres at 5 persons/acre, perpcc07 is employment density centres at 7 persons/acre, perpcc10 is employment density centres at 10 persons/acre and perpcco is employment densitycentres at the regional average)

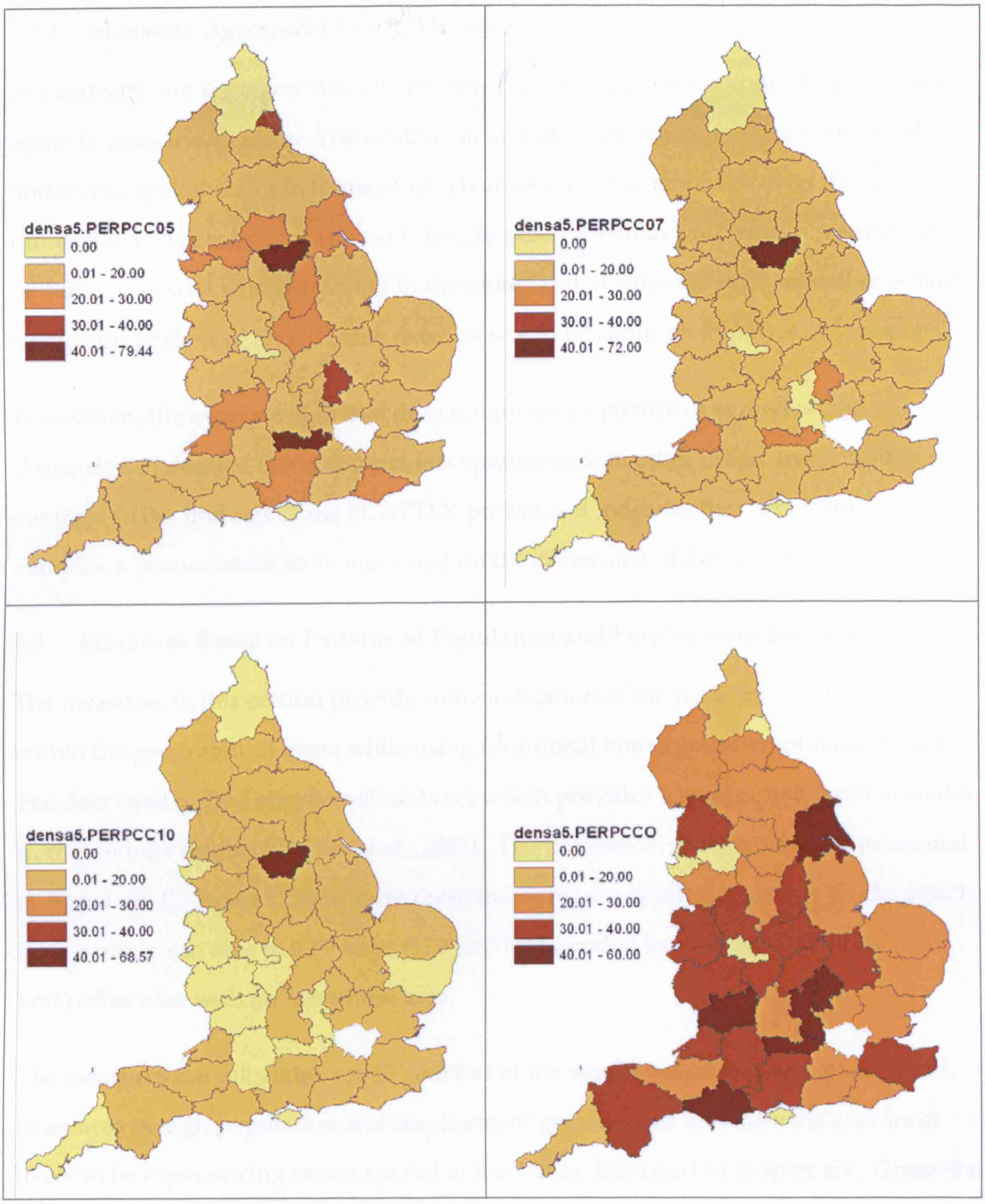


Figure 7.16: Maps of population living outside central cities (perpcc)

(perpcc 05 is employment density centres at 5 persons/acre, perpcc07 is employment density centres at 7 persons/acre, perpcc10 is employment density centres at 10 persons/acre and perpcco is employment densitycentres at the regional average)

7.2.1 *Summary Aggregate Density Measures*

In summary, the aggregate density measures of sprawl present a conflicting picture of sprawl across the 44 areas. The relative picture of sprawl changes with each measure and across spatial scales in terms of which areas score higher or lower on the sprawl dimensions. Aggregate measures of density pose particular problems in measuring patterns of sprawl where densities in the hinterland of cities are high overall or where significant pockets of high density exist, as would be common in polycentric regions.

In addition, the example of Bristol does not present a picture of sprawl on the dimension of density, but it appears less sprawling than other urban areas. This is contrary to the findings of the SCATTER project and indicates that urban sprawl is too complex a phenomenon to be measured on the dimension of density alone.

7.3 Measures Based on Patterns of Population and Employment Density

The measures in this section provide some indication of the patterns of urban sprawl within the geographical areas while using traditional housing and employment data. The data used is the Code-Point® data set which provides a level of detail not available from previous studies (Galster et al., 2001). The patterns in the raw data are presented in Appendix C. In the US literature these measures are applied to census blocks which have a minimum area of 0.69 acres (170 km^2) if bounded by roads or 0.92 acres (227 km^2) otherwise with no maximum area.

The measures are calculated for 10 counties in the south east of England, plus Bristol, as an area of high population and employment growth, and therefore the area most likely to be experiencing urban sprawl in the UK as discussed in chapter six. Given the small sample size (11 areas), no tests of significance were carried out for these measures as the power of such tests would be low.

The concentration indicator shows the extent to which development is concentrated in a relatively small portion of the study area rather than spread evenly throughout. Concentration is higher for county and travel to work areas which are fairly similar and lower for district and urban areas, with the average values ranging from 0.43 to

0.67, a moderate to high level of concentration (see Table 7.6 and Figures 7.17 and 7.18). A lower level of concentration has been associated with greater levels of sprawl (Galster et al., 2001), which these results contradict. However at high densities, particularly in older urban areas which would have higher levels of development, a lower level of concentration can be expected as a high density urban area has a pattern of high density development spread evenly across the urban area, thus resulting in lower levels of concentration. The measure does not take the density of development into account in assessing the level of concentration except as setting a bench mark for the minimum level of development necessary for the area to be considered as developed rather than as non developed land.

The measure does not provide much distinction among the eleven areas, with the travel to work scale showing the most variation on this measure as in Figure 7.17. The map scale for the urban area does not match those for the county, travel to work, and district areas in order to present a suitable classification, as the results for the urban area fall within the minimum category on the other spatial scales.

Table 7.6: Summary statistics for concentration

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
county	0.57	0.72	0.67	0.04	-1.36	2.48
district	0.42	0.73	0.54	0.10	0.89	0.06
urban	0.36	0.51	0.43	0.04	0.04	0.42
TTW	0.48	0.72	0.66	0.07	-1.77	3.38

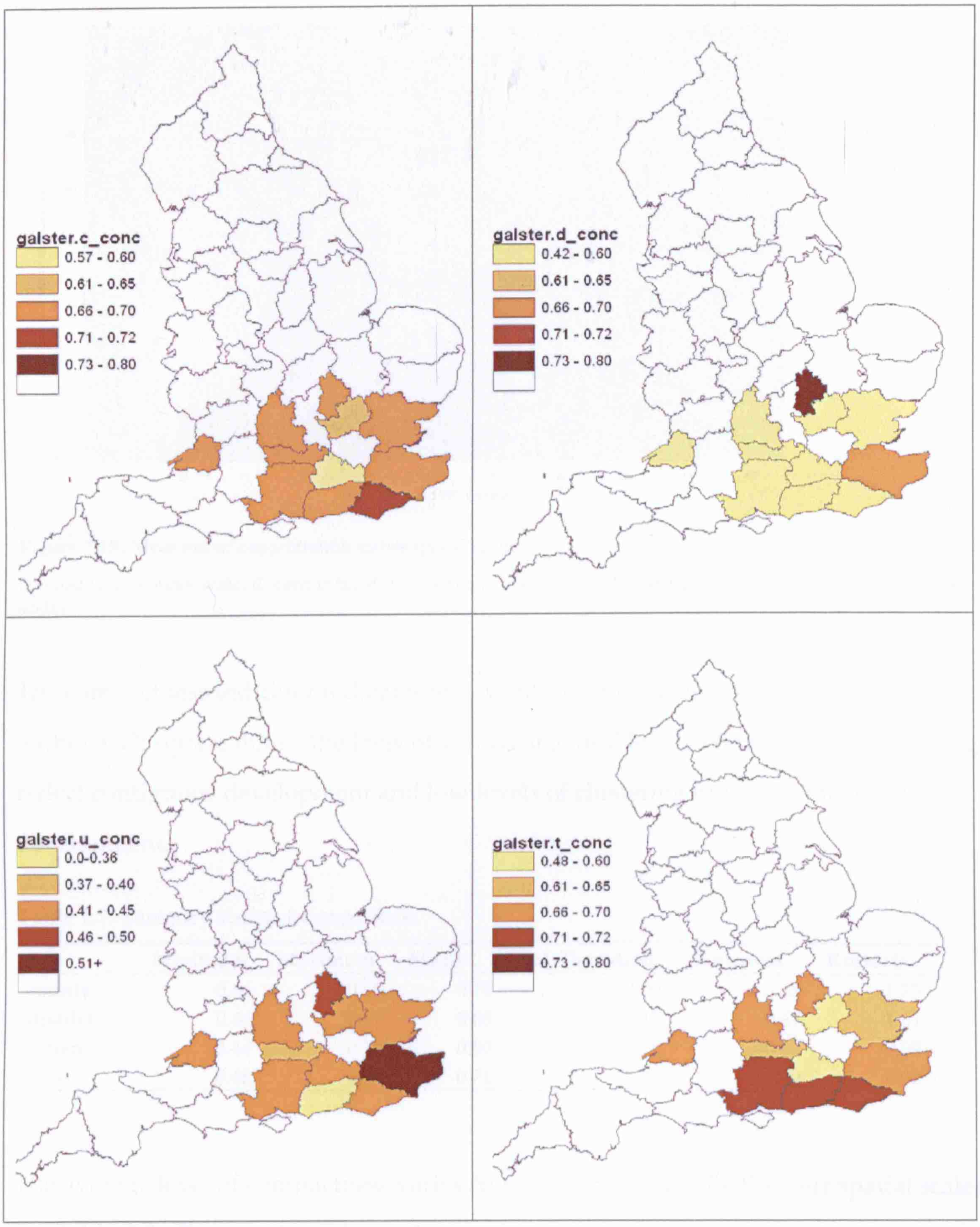


Figure 7.17: Maps of measures of concentration

(c_conc is the county scale, d_conc is the district scale, u_conc is the urban scale and t_conc is the travel to work scale)

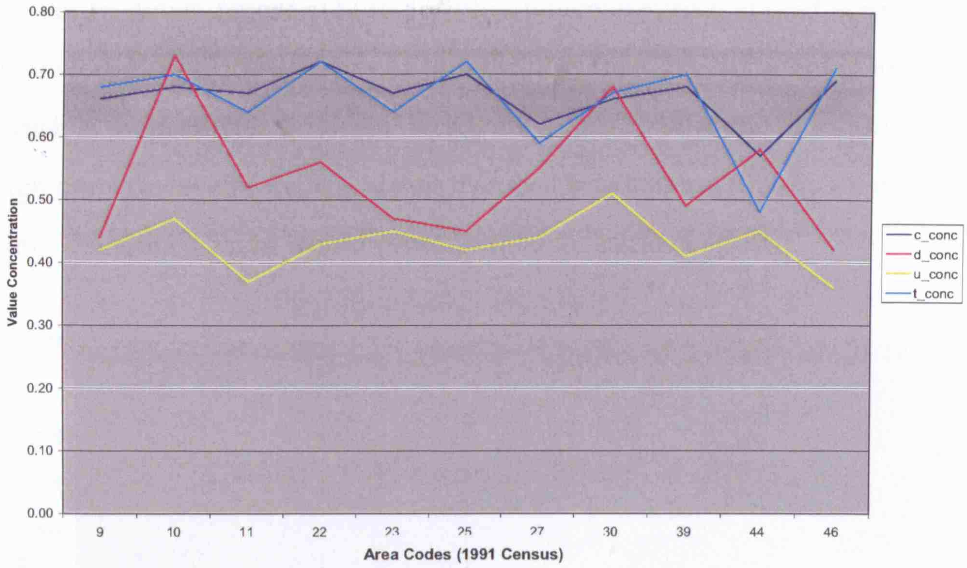


Figure 7.18: Measures of concentration across spatial scale

(c_conc is the county scale, d_conc is the district scale, u_conc is the urban scale and t_conc is the travel to work scale)

The compactness indicator indicates the extent to which development is clustered within each square mile – the level of sprawl at a local level. High levels of clustering reflect contiguous development and low levels of clustering indicate more scattered development.

Table 7.7: Summary statistics compactness

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
county	0.66	0.98	0.79	0.09	0.67	1.73
district	0.44	0.91	0.69	0.17	-0.47	-1.51
urban	0.44	0.71	0.60	0.10	-0.67	-0.99
TTW	0.48	0.94	0.71	0.13	0.19	0.05

The average level of compactness varies from 0.60 to 0.79 across the four spatial scales, see Table 7.7. The county and travel to work areas have the highest scores for compactness with the district and urban the lowest. The level of compactness ranges from moderate to low as in Figures 7.19 and 7.20. The Bristol area has very low levels of compactness for the district and urban area as development is at a fairly high density but encompasses the entire spatial area. The results are again contradictory to the literature, as the urban and district areas would be expected to have higher levels of compactness as development at these scales would be more contiguous.

However, development at high densities which is evenly spread across each square mile would show lower levels of compactness than development at lower densities which is more clustered within the square mile. As with the measure of concentration, high density development which is evenly spread across the square mile, as is likely in more developed areas would confound the measure of sprawl.

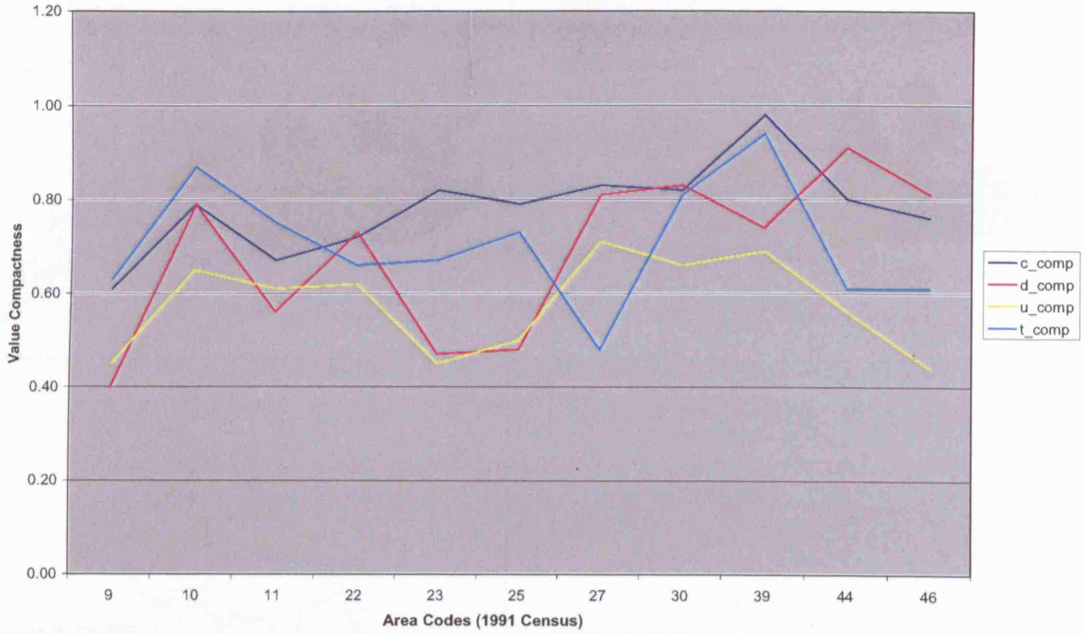


Figure 7.19: Results for compactness across spatial scales

(c_comp is the county scale, d_comp is the district scale, u_comp is the urban scale and t_comp is the travel to work scale)

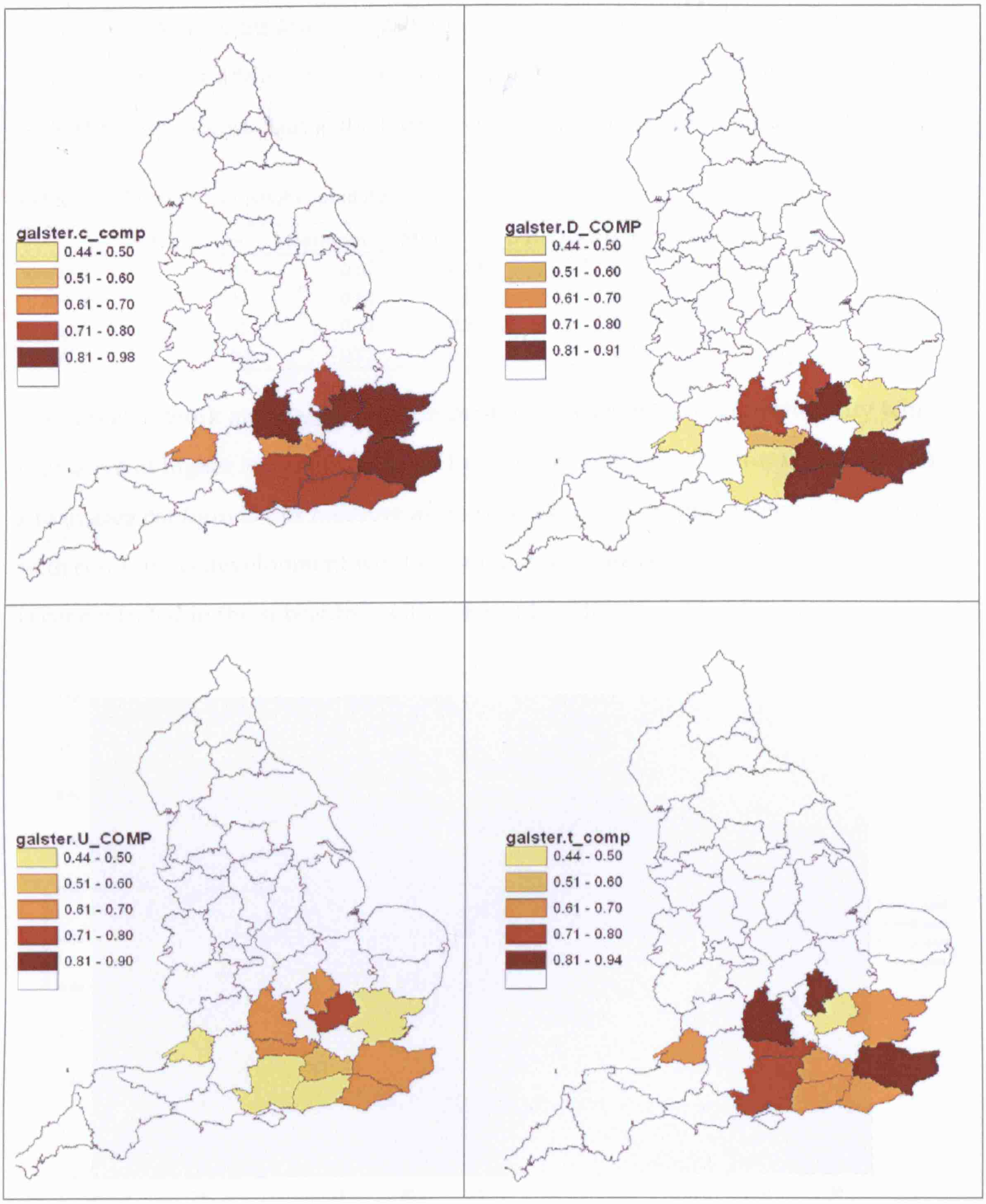


Figure 7.20: Maps of compactness

(c_comp is the county scale, d_comp is the district scale, u_comp is the urban scale and t_comp is the travel to work scale)

The measure of continuity shows the degree to which land has been built on in an unbroken fashion. The average level of continuity ranges from 0.46 to 0.86 (see Table 7.8). The urban scale shows the highest levels of continuity with the county and the travel to work scale the lowest. The difference between the district and urban scales and the county and travel to work scales are quite marked with the urban and district scale showing almost double the level of continuity, as we see in Figures 7.21 and 7.22.

Table 7.8: Summary statistics continuity

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
county	0.29	0.62	0.43	0.08	0.64	2.15
district	0.29	0.81	0.62	0.16	-0.98	0.28
urban	0.81	0.92	0.86	0.04	-0.16	-0.97
TTW	0.29	0.72	0.46	0.13	0.84	0.81

The travel to work and county areas in Bristol show lower levels of continuity which is indicative of higher levels of sprawl. However the polycentric nature of the Bristol urban area confounds this measure as polycentric areas, despite having urban centres with contiguous development would result in low scores of continuity as development is concentrated in the subcentres with areas of less developed land in between.

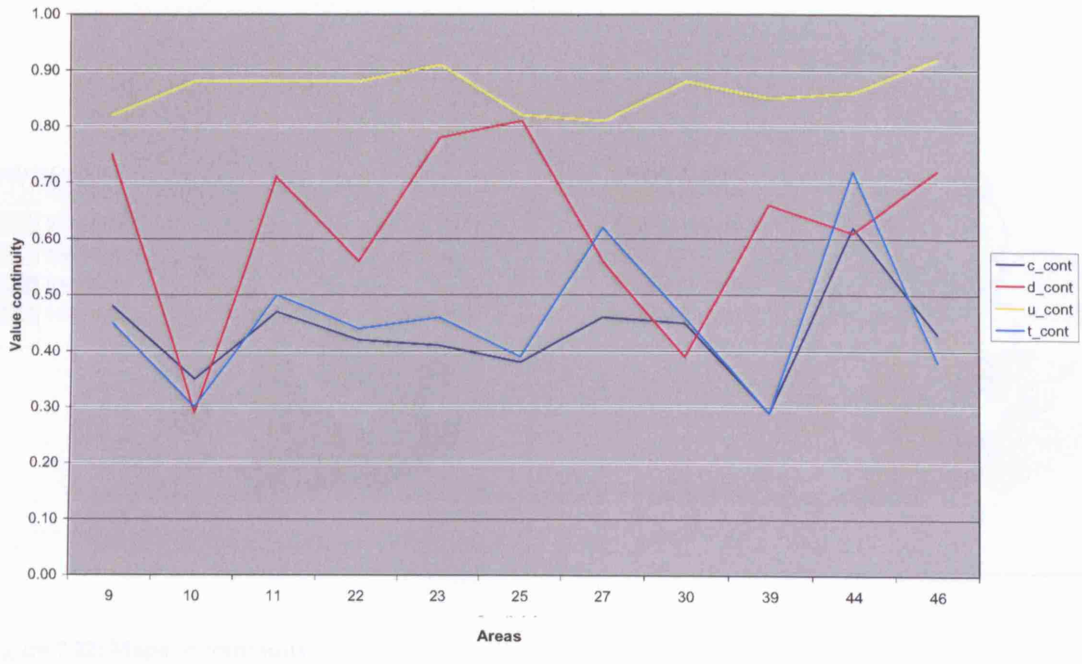


Figure 7.21: Results for continuity across spatial scales

(c_cont is the county scale, d_cont is the district scale, u_cont is the urban scale and t_cont is the travel to work scale)

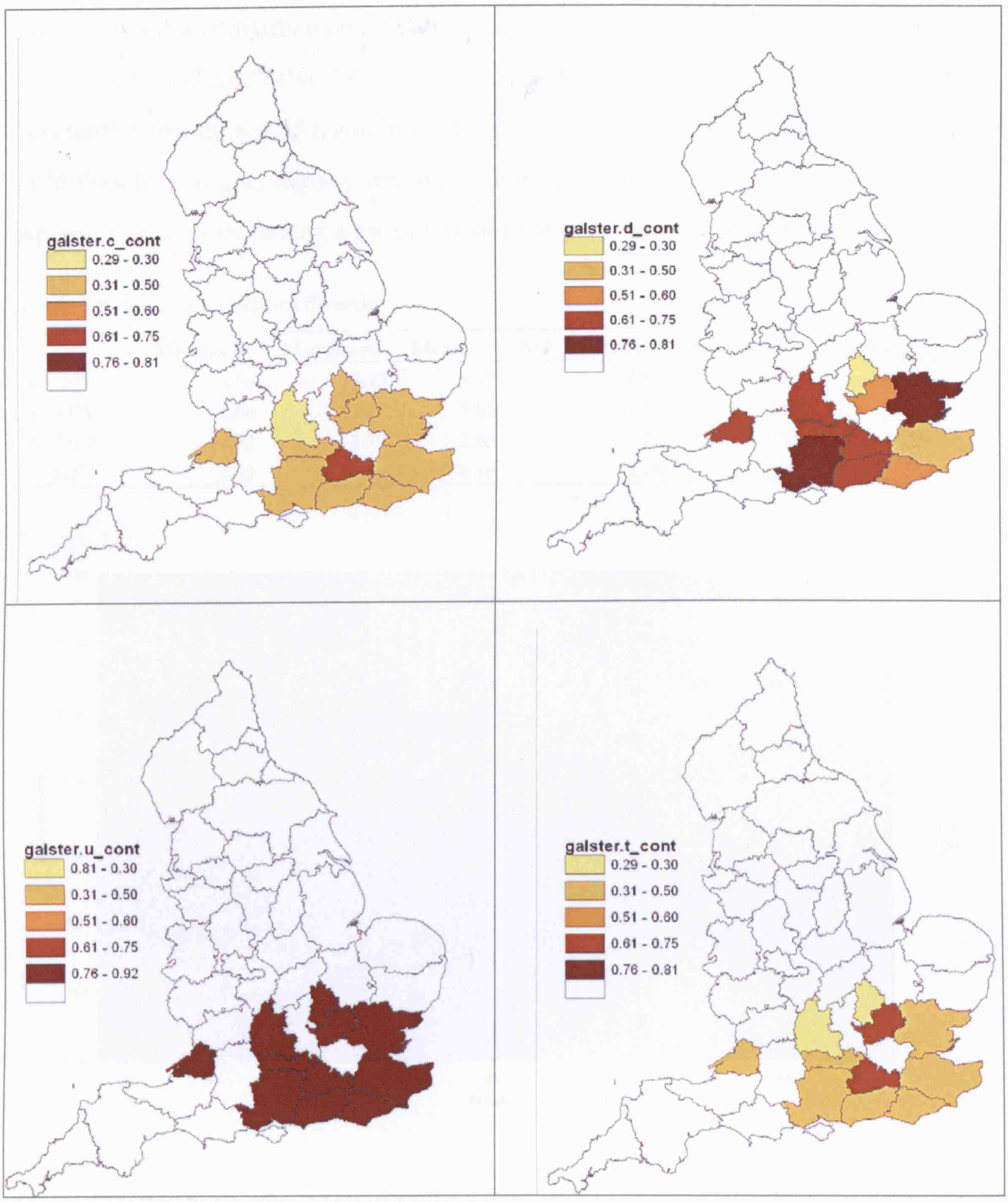


Figure 7.22: Maps of continuity

(c_cont is the county scale, d_cont is the district scale, u_cont is the urban scale and t_cont is the travel to work scale)

Diversity measures the degree to which residential and business uses exist within the same square mile, and indicates the extent of mixing at the small area level within the one mile square grid. The level of diversity is higher for the county and travel to work scales than the urban and district scale, with the mean level of diversity varying from 2.66 to 6.17 (see Table 7.9, Figures 7.23 and 7.24). An area with a lower overall residential density would result in a higher diversity score, all other things being equal. Additionally, a higher density area would have a predominance of one use within the square mile despite having a greater mixture of uses over the area as a whole.

Table 7.9: Summary statistics diversity

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
C_DIV	3.50	9.40	6.17	1.81	0.39	-0.43
D_DIV	2.06	12.27	3.85	2.98	2.66	7.67
U_DIV	1.80	4.10	2.66	0.75	0.78	-0.73
T_DIV	2.30	10.69	6.16	2.26	0.37	0.68

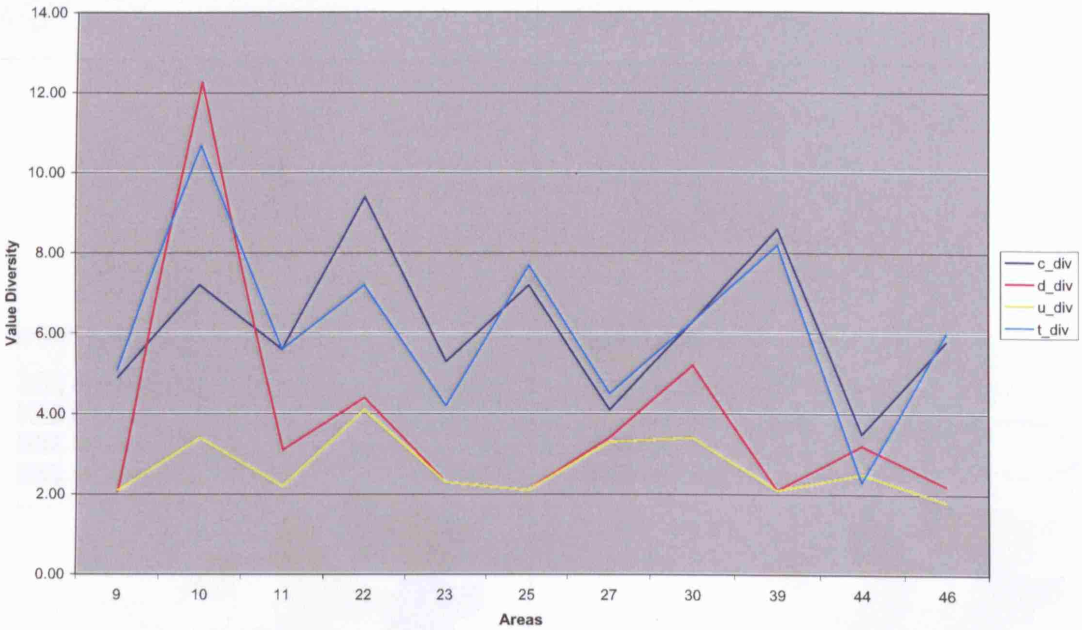


Figure 7.23: Results for diversity across spatial scales

(c_div is the county scale, d_div is the district scale, u_div is the urban scale and t_div is the travel to work scale)

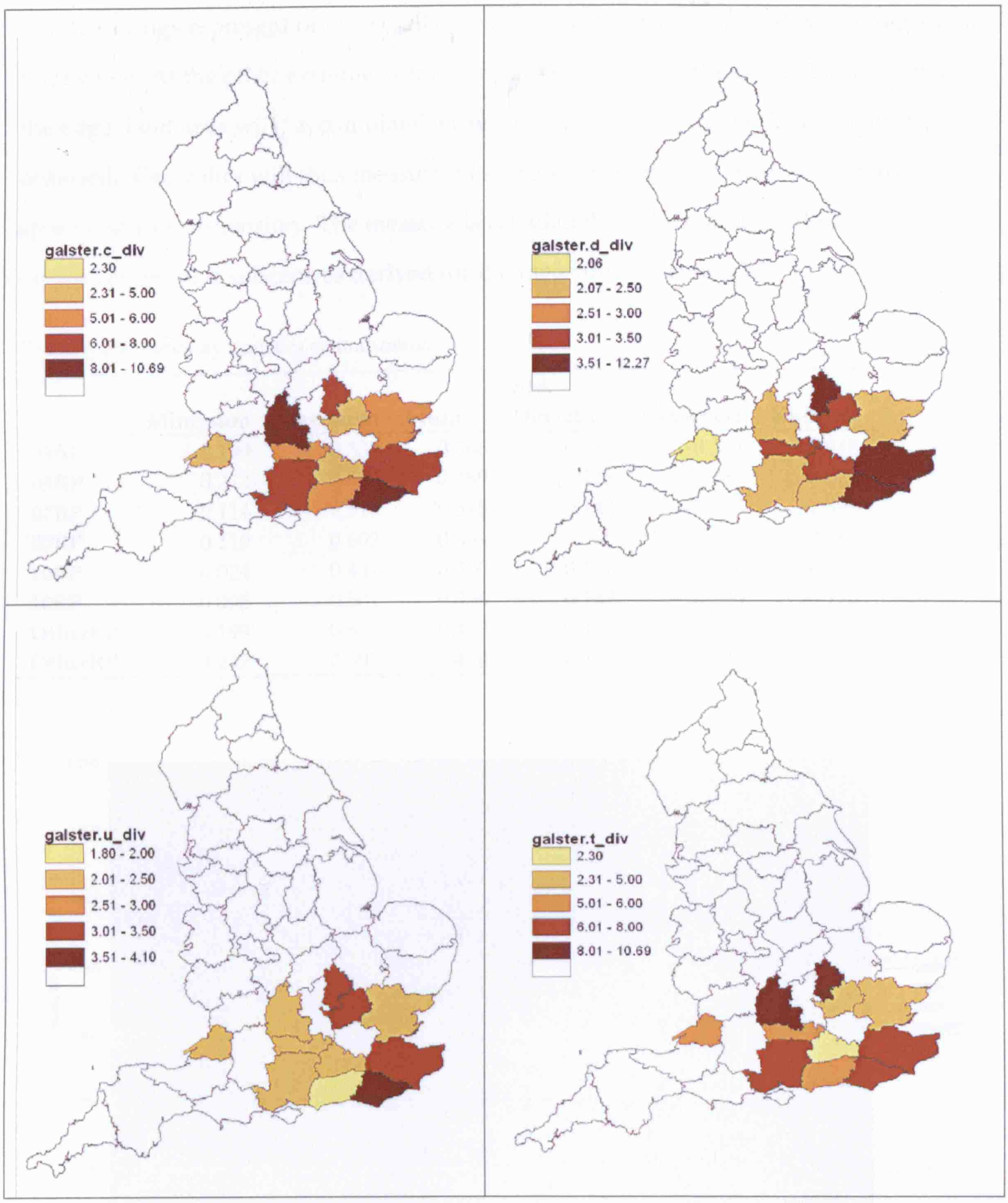


Figure 7.24: Maps of Diversity

(c_div is the county scale, d_div is the district scale, u_div is the urban scale and t_div is the travel to work scale)

Centrality measures the extent to which business or residential uses are located close to the centre based on the cumulative distance of the land uses to the centre. If virtually all of the observations of a particular land use accumulate within the innermost rings but these rings represent only a small fraction of the total area, centrality will register a high value. At the other extreme, if few uses are located near the center but most near the edge, land area will "accumulate" faster than will the particular land use moving outward. Centrality will thus measure a low value, signifying a greater degree of sprawl on this dimension. The measure is calculated for the county scale and is based on the centres and subcentres derived for the measures in section 7.2

Table 7.10: Summary statistics centralization

	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
05BP	0.139	0.537	0.366	0.110	-0.351	0.918
05RP	0.212	0.602	0.389	0.118	0.780	0.327
07BP	0.114	0.519	0.315	0.143	-0.035	-1.395
07RP	0.119	0.607	0.354	0.150	0.126	-0.789
10BP	0.024	0.447	0.300	0.137	-0.676	-0.298
10RP	0.095	0.501	0.338	0.132	-0.483	-0.770
OtherBP	0.199	0.583	0.453	0.113	-1.090	1.201
OtherRP	0.237	0.597	0.478	0.105	-1.132	1.592

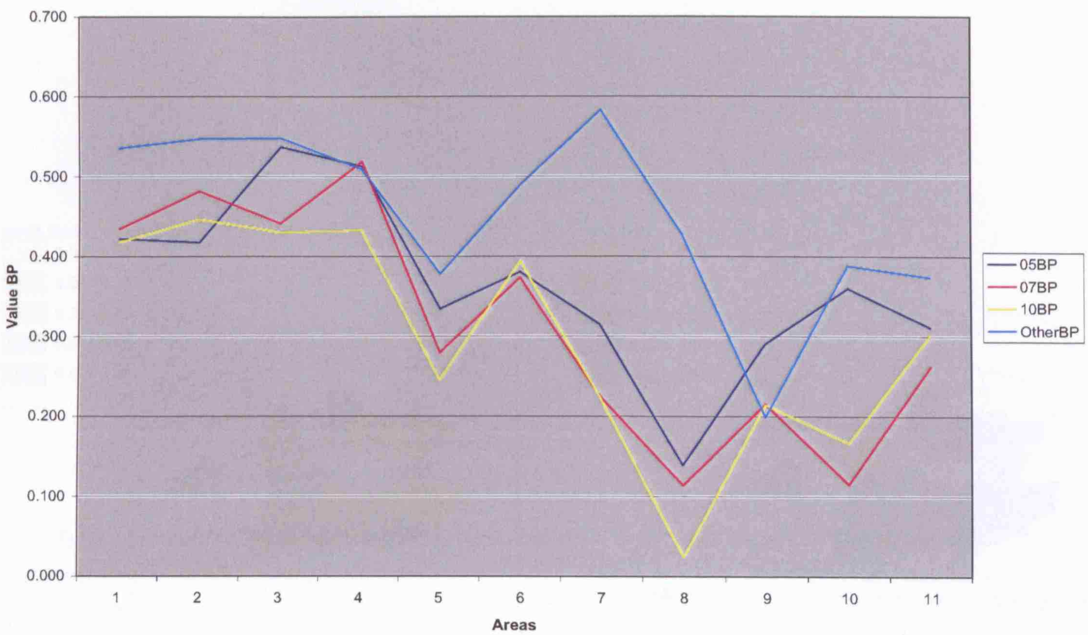


Figure 7.25: Centralization of business use across spatial scales (05bp is business centralization with employment centres defined at 05 businesses per acre, 07bp is business centralization with employment centres defined at 07 businesses per acre, 10bp is business centralization with employment centres defined at 10 businesses per acre, otherbp is business centralization with employment centres defined at the regional average of businesses per acre)

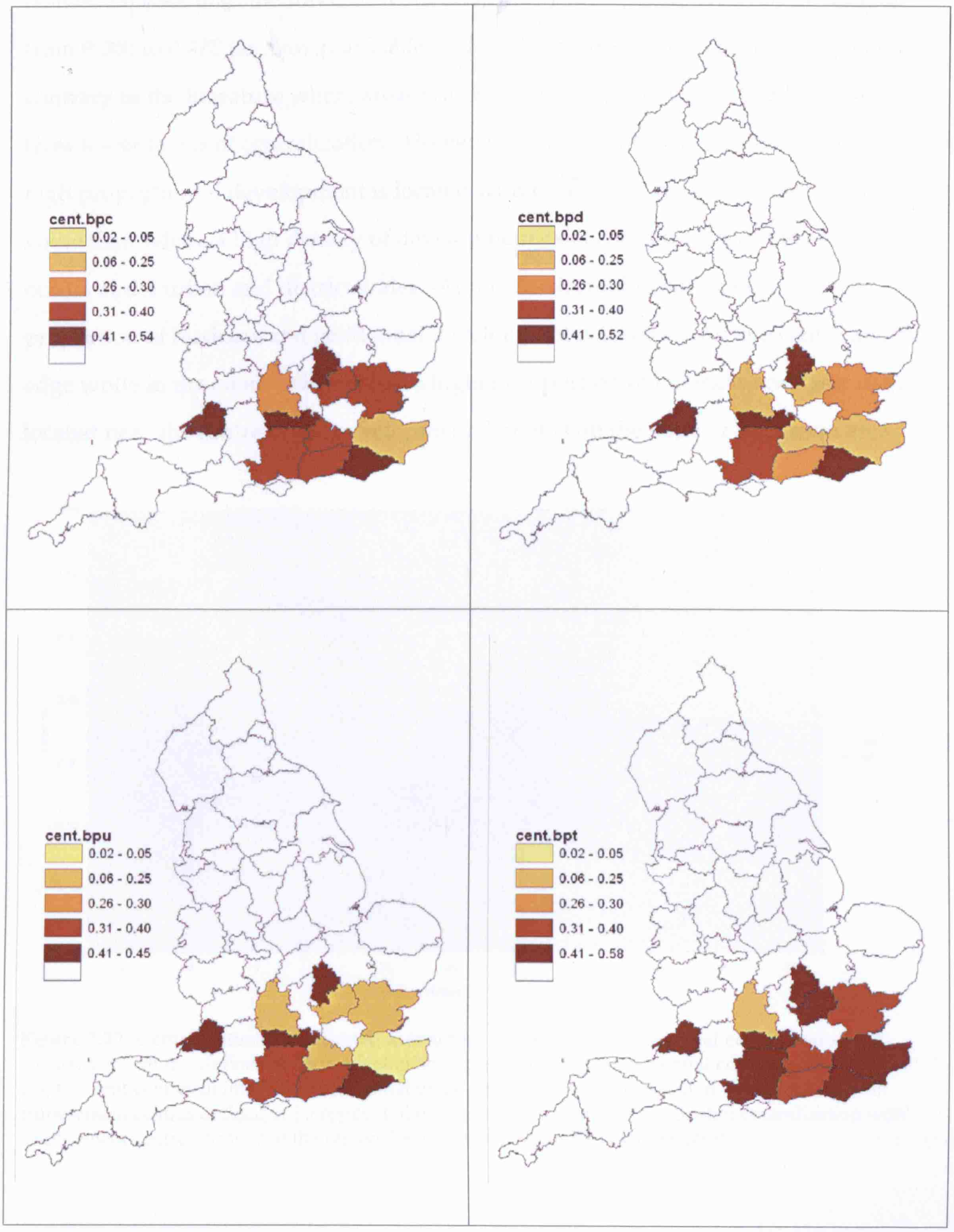


Figure 7.26: Maps of centralization of business uses across scales (05bp is business centralization with employment centres defined at 05 businesses per acre, 07bp employment centres defined at 07 businesses per acre, 10bp employment centres defined at 10 businesses per acre, otherbp is business centralization with employment centres defined at the regional average of businesses per acre)

The district and urban areas have lower levels of centralization for business and residential uses than the travel to work and county areas, with the average ranging from 0.300 to 0.478 (as shown in Table 7.10, and Figures 7.25 to 7.28). This is again contrary to the literature where areas which are more sprawling would be expected to have lower levels of centralization. However, at the county and travel to work scales, a high proportion of development is located within the inner two rings registers a higher value than where a high density of development exists on the edge of the area which occurs at the urban and district scales. At the district and urban scales, an even proportion of business and residential development is located near the centre and the edge while in the county study area, a higher proportion of business and land use is located near the centre of the development than it is on the edge of the urban area.

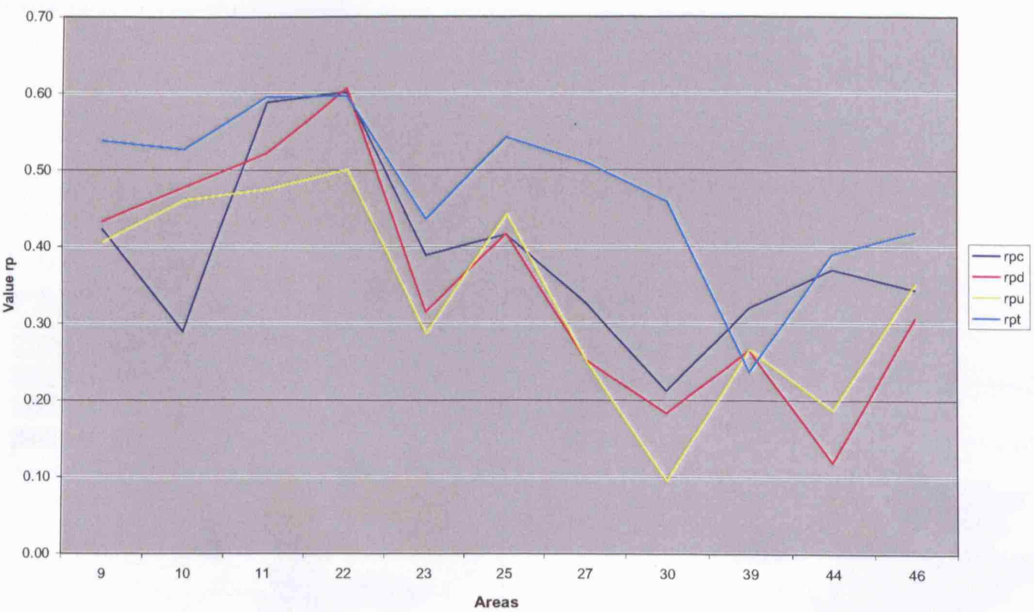


Figure 7.27: Centralization of residential uses across scales (05bp is residential centralization with employment centres defined at 05 residential units per acre, 07bp is residential centralization with employment centres defined at 07 residential units per acre, 10bp is residential centralization with employment centres defined at 10 residential units per acre, otherbp is residential centralization with employment centres defined at the regional average of residential units per acre)

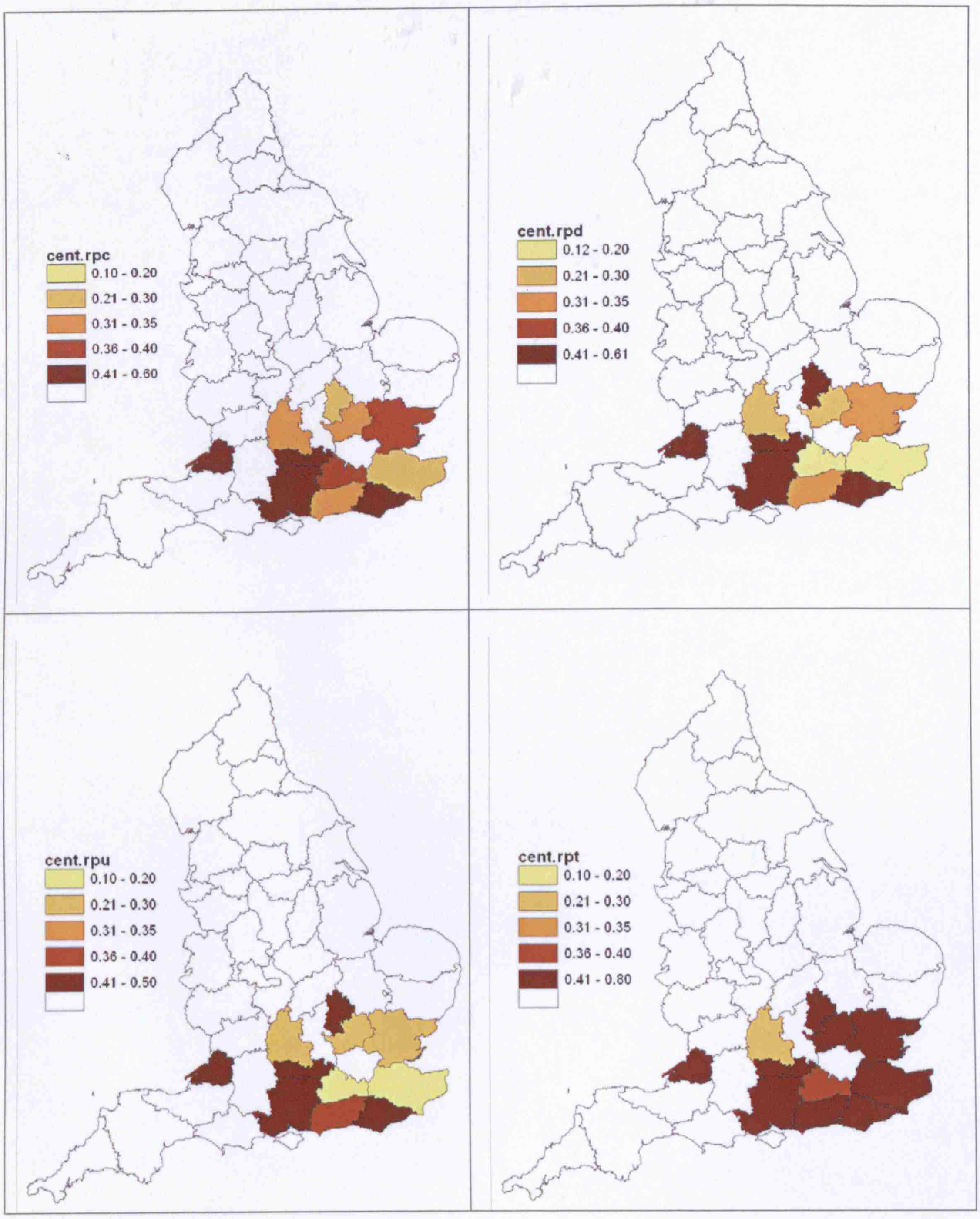


Figure 7.28: Centralization of residential uses across scales (05bp is residential centralization with employment centres defined at 05 businesses per acre, 07bp is residential centralization with employment centres defined at 07 businesses per acre, 10bp is residential centralization with employment centres defined at 10 businesses per acre, otherbp is residential centralization with employment centres defined at the regional average of businesses per acre)

7.3.1 *Summary Measures of Population and Employment Pattern*

The measures of urban sprawl based on population and employment patterns show that the choice of area for the study of urban sprawl greatly influences the results. This has not been recognized by previous studies which have applied measures of sprawl to the urban area, without including the urban fringe, thus underestimating the presence of urban sprawl. The results for the county and travel to work areas are similar, which verifies the choice of the county area as the unit of study for the SCATTER project. However, where there are travel to work connections to other major cities, this may bias the results, as seen with the measure of continuity. The district and urban areas also show similar results. However unlike the aggregate measures, differences are evident based on whether the district matches the urban area or is defined as a separate area.

The measures are also confounded by the high densities, particularly when considering the 1 mile square area. The measures of compactness and concentration show lower values (with lower values indicative of urban sprawl) for the urban and district areas than for the travel to work and county areas, despite the latter having higher levels of sprawl. In these cases, the measures are confounded by the high densities throughout the area which results in an even spread of development albeit at a high density. Although the measures indicate low levels of compactness and concentration in the urban and district areas, the high densities present implies that the characteristics of urban sprawl are not present. This discrepancy needs to be accounted for if these measures are to be used in the European context.

7.4 Measures of Sprawl Based on Land Use Patterns

This section examines the application of land cover measures to the Bristol area. It does not provide a comparison between the four spatial scales of the county, district, travel to work and urban, as the urban and district areas are at too small a scale for application of the landscape ecology measures, but the intention is to examine the potential impact of administrative boundaries on measures of sprawl.

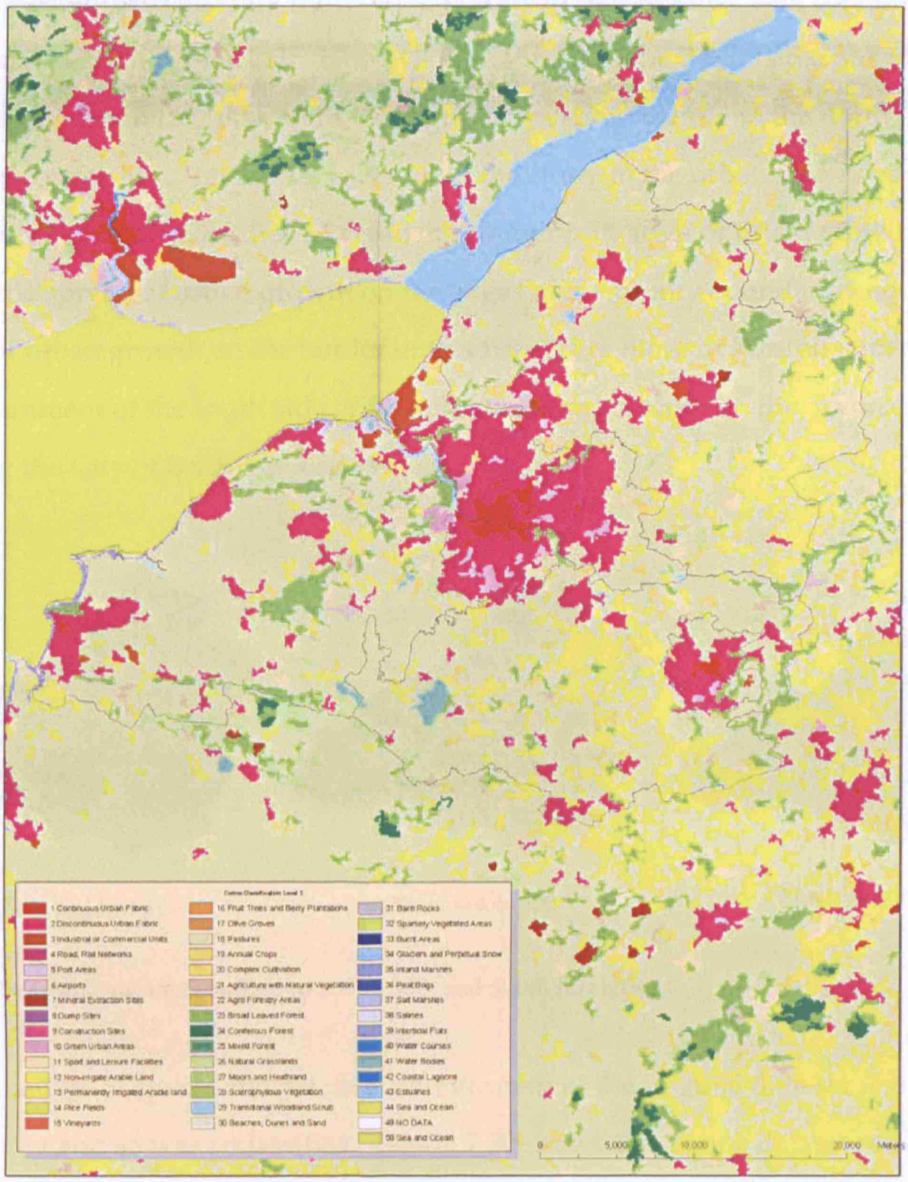
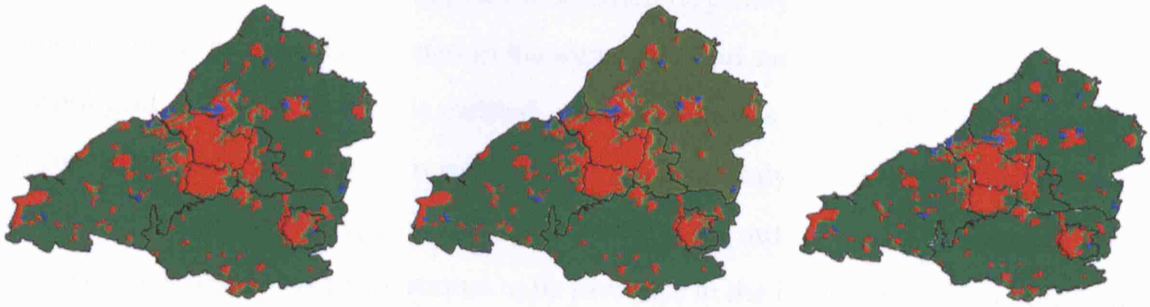


Figure 7.29: Corine dataset for the Bristol area

Figure 7.29 shows the Corine landcover map for the Bristol Area (the former county of Avon) with the local authority boundaries outlined in grey. The two main cities in the region, Bristol and Bath, can be identified by the larger patches of continuous and discontinuous urban fabric (shown in pink and red). There are patches of urban land outside of these centres, but the main land cover type is arable land, and pastures with some forested areas. The version used is the Corine land cover 100m resolution for 1990, as discussed in section 6.

A visual inspection of the data shows that the City of Bath is fairly well contained due to the presence of the green belt. However, the spread of the Bristol area outside of its administrative boundary is evident, with growth pushing mainly to the north east into South Gloucestershire. Measures which limit the study to the urban area as opposed to the wider regional area are thus likely to miss significant areas of urban growth. There is very little spread of urban growth on the edges of the county boundary, and the patches of urban growth on the border of the district are those of Weston-super-Mare. The containment of the south side of Bristol due to the presence of the Avon estuary bordering the City of Bristol is also evident.



100m resolution 300m resolution 500m resolution

Figure 7.30: Corine data reclassified to 100m, 300, and 500m resolutions

For the analysis of sprawl the detailed classification of the original data set was unnecessary and so was reclassified. Figure 7.30 shows the Corine dataset reclassified to three classes: urban, commercial and industrial and non urban, at three scales. Details of the reclassification are covered in chapter six. Red represents urban land cover, blue represents commercial and industrial, and green represents non urban. The division of built-up areas into urban, and commercial and industrial was considered to be important for evaluating the extent of mixed use of the landscape. The images have also been rescaled to three resolutions: a 100m resolution, a 300m resolution and a 500m resolution using ArcGIS, as the results of the measures vary according to the resolution of the image. The main impact of the rescaling is that the edges of each patch become increasingly stepped at finer resolutions, and the number of patches decreases at larger resolutions as the patches are amalgamated. The nearest neighbour method of resampling was used as it is applicable to discrete value types, and it provides output values which are the original input values. This method assigns to the output cell the input value which is closest to the centre of each output cell.

Other methods of resampling using spatial interpolation include bi-linear interpolation which uses the weighted average of the nearest four pixels to the output pixel and cubic convolution which uses the weighted average of the nearest sixteen pixels. These methods cause a loss of original data as the neighbouring values are averaged together. As well as spatial interpolation methods, spatial aggregation methods such as the majority rule method and the random rule aggregation can be used. The majority rule method assigns the value that appears most often (typically over 50 percent of the time) for the cells to be aggregated in the input grid and assigns that value to the output grid. However with this method, dominant classes increase and minor classes decrease or disappear. Random rule aggregation randomly selects a cell from the input grid cells to be aggregated and assigns that to the output grid. The probability that a class is selected is proportional to its presence in the input data which may lead to disaggregated spatial patterns. These methods were seen as less suitable than nearest neighbour resampling as original data is lost.

7.5 Measures of Landscape Composition

The measures of landscape composition examined and the relationship to urban sprawl are:

- Patch Density (PD) which is the number of patches in a landscape divided by the total landscape area. A landscape with a higher density of patches has a finer grain, with the potential for increased heterogeneity or fragmentation of development. Patch density, patch size, and patch edge emphasise the overall contribution of different land use categories to the landscape configuration. However patch density in isolation provides no information about the size or distribution of patches, which indicates whether urban areas are compact or fragmented.

- Largest Patch Index (LPI) measures the percentage of total landscape area comprised by the largest patch, which gives some indication of the extent of compact development in the area.

- Total Class Area (CA) shows the size of the urban area in comparison with the rest of the landscape.

- Percentage Land Area (PLAND) shows the percentage of land area for each land use class.

- Patch Size Standard Deviation (PSSD) indicates the variability in the size of the patches. A large variability in the patch size is indicative of a large core with several scattered areas. In two areas with a similar patch size standard deviation, an area with smaller patch sizes would have greatly varying and smaller patches, while one with larger patch sizes would have uniformly sized and larger patches. Patch size standard deviation indicates the scatter of urban development and its encroachment on rural areas, with higher values indicating higher levels of sprawl when accompanied by smaller patch sizes.

- Nearest Neighbour Distances (ENN_MNN) is the distance from a patch to the largest neighbouring patch of the same type, based on edge to edge distance. This provides some indication of the spread of development within the landscape. The higher the value, the greater the level of sprawl.

- Edge Density (ED) standardizes edges to a per unit area basis that allows for comparison among landscapes of varying sizes. It measures the total edge of all patches in a particular class. This is used to show which land uses dominate an area. The higher the edge density, the more scattered the development.

- Contagion (CONTAG) represents the spread and intermixing of patch types. It is calculated by looking at cell adjacencies which measures the extent to which cells of a similar class are aggregated. Smaller values describe a landscape of many small, unconnected patches or higher levels of sprawl; higher values define larger contiguous patches or more compact development. This metric does not account for the number and size of patches, so several large but compact patches can produce a low value of contagion.

- Interspersion and Juxtaposition Index (IJI) reflects the extent to which all patch types are intermixed and is measured for residential, commercial and non urban land uses. All three classes are used as this metric measures adjacency of patches rather than cell adjacency. Contagion and Interspersion are inversely related to each other, and higher contagion usually results in lower interspersion. The higher the level of interspersion, the greater the mix of development

- Division (DIVISION). Neither contagion nor interspersion consider the number or size of patches, both of which are necessary to measure the extent of uncontrolled urban growth. The division measure takes this into account by looking at the aggregation of patch types and at the number and size of the patches. Large, contiguous patches result in low values for the division metric while small discontinuous patches result in higher values indicating higher levels of sprawl.

Further explanations of landscape ecology metrics are given in Forman (1995) and Forman and Godron (1986).

7.6 Results of the Measures of Land Cover Pattern

The results for total class area (CA) metric, as shown in Figure 7.31, shows Bristol with a high value for size of the urban area, reflecting the almost complete urbanization of this area. Bath and North East Somerset has a low value as a large proportion of the area is composed of green belt. The total class area is lower than that for North Somerset and South Gloucestershire despite Bath and North East Somerset containing the second largest city in the region. The total class area metric is complemented by the percentage of land area (PLAND) metric, as in Figure 7.31 which shows that the urban area comprises most of the landscape for Bristol, around 80 percent. On this measure, however, Bath and North East Somerset has a similar level of urbanization as North Somerset and South Gloucestershire, around 10 percent, at all scales.

The number of patches (NP) in Figure 7.31, in conjunction with the percentage land area in urban use and the total class area can provide some indication of the level of dispersion of development in the landscape. The greater the sprawl, the higher the number of patches and the lower the percentage of land or class area in urban use and the smaller the patch size. Bristol has a very low number of patches, ranging from 3 to 8 followed by North Somerset with 34 to 46 patches, South Gloucestershire with 29 to 33 patches, and Bath and North East Somerset with 19 to 24 patches. This is in accordance with the results of the qualitative study where Bristol was seen as the most compact urban area. South Gloucestershire, however, is more dispersed than Bath and North East Somerset which is not indicated by this measure. The number of patches in isolation provides insufficient information as a measure of sprawl as it gives no information on the size of the urban area.

In terms of largest patch size (LPI) Bristol as shown in Figure 7.32, with an average patch size of 73 m^2, has a much larger patch size than, South Gloucestershire and North Somerset, with patch sizes of 2 to 3 m^2, at all resolutions indicating a high level of urbanization and amalgamated development. In general, mean patch size has a tendency to increase at larger resolutions as small sliver patches are amalgamated. The small but compact city of Bath registers a slightly higher LPI, with an average of 5 m^2.

A high value for patch density, as shown in Figure 7.32 indicates higher levels of urbanization and lower levels of sprawl. Despite this, the patch density for residential land use is lowest for Bristol, with an average of 0.05 patches per 100 hectares, which has lower levels of sprawl based on other measures. The Bristol area contains a single, large patch which accounts for the low density despite it being the most urbanized area. However, the patch density is similar for Bath and North East Somerset, South Gloucestershire and North Somerset, particularly at the 100m resolution (with averages of 0.06, 0.07, and 0.11 patches per 100 hectares respectively).

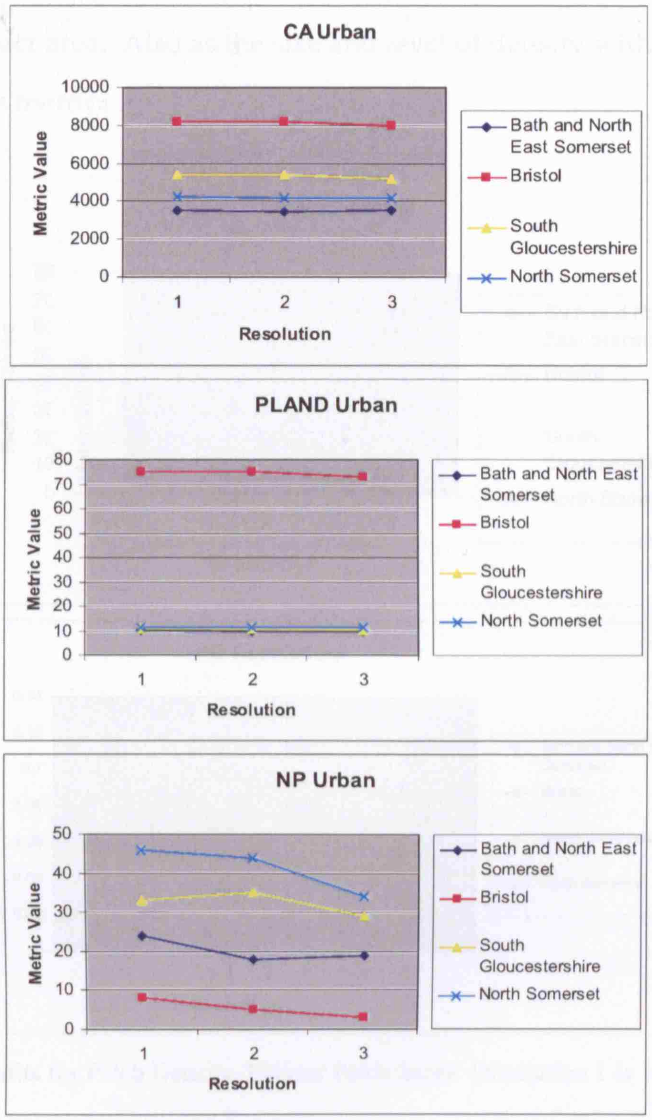
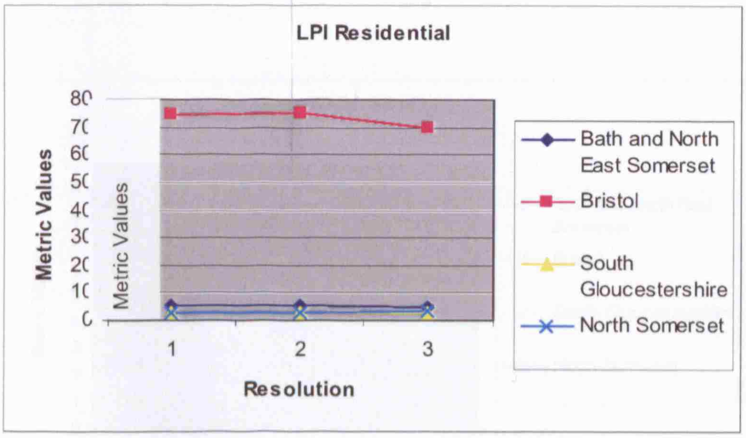


Figure 7.31: Results for Total Class Area, Percentage Land Area, Number of Patches and Mean Patch Size (resolution 1 is 100m, 2 is 300m and 3 is 500m)

The difference in configuration between Bath and North East Somerset, and South Gloucestershire and North Somerset is not apparent from this measure, as the more fragmented nature of development in the two latter areas is not indicated by this metric. Comparison of the three spatial resolutions results in a sharp decrease in patch density as the resolution increases; this is particularly true for residential use in Bristol. This decrease in the patch density can be attributed to the amalgamation of small sliver patches at coarser resolutions. The patch density measure in isolation has not provided accurate identification of the extent of urban sprawl in the area, largely due to its identification of small, sliver patches as separate areas of development, in what is otherwise a compact area. Also as the size and level of density within the patch is not considered by this metric.



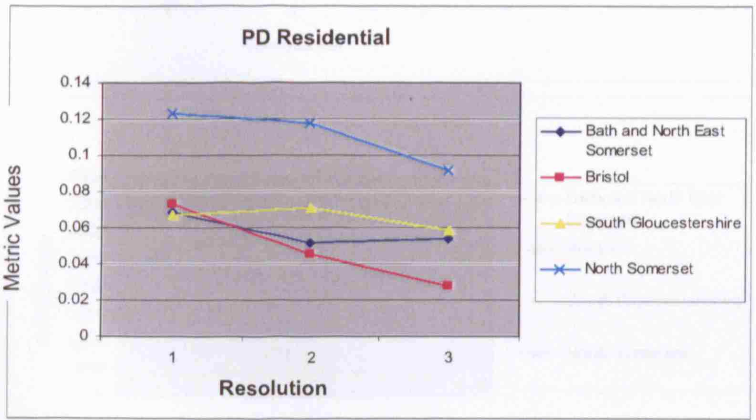


Figure 7.32: Results for Patch Density, Largest Patch Index (resolution 1 is 100m, 2 is 300m and 3 is 500m)

The results for the edge density measure, shown in Figure 7.33, show Bristol as having the highest residential density, with an average of 6.8 m per hectare, identifying the urban nature of the area. Bath and North East Somerset, South Gloucestershire and North Somerset have averages of 3.9, 4.3 and 5.1 m per hectare respectively. While this measure identifies Bristol as having higher residential densities, the distinction between Bath and North East Somerset and South Gloucestershire and North Somerset is not made clear.

A patch size standard deviation, as in Figure 7.33 with a large variability in the size of the patches indicates that there is a large core with several scattered areas. Patch size standard deviation is often interpreted together with patch size. Given two areas with a similar patch size standard deviation, an area with smaller patch sizes would have greatly varying and smaller patches, while one with larger patch sizes would have uniformly sized and larger patches.

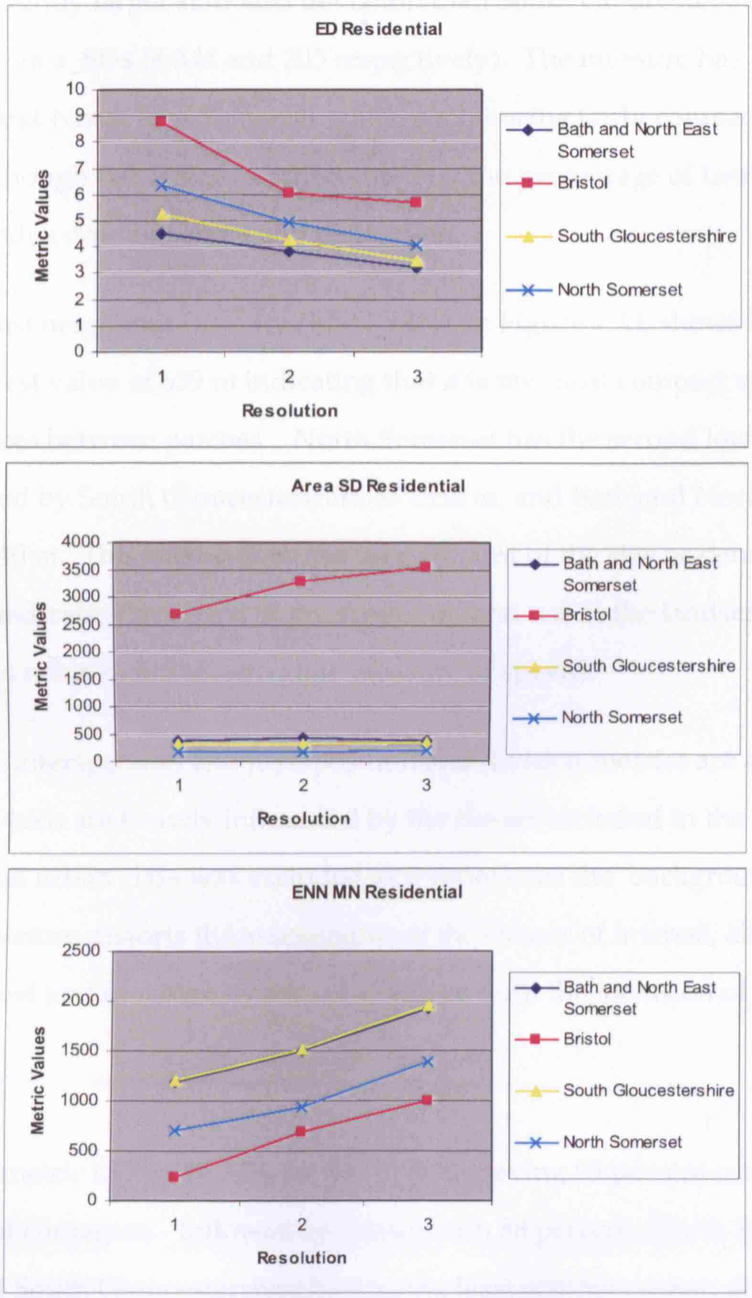


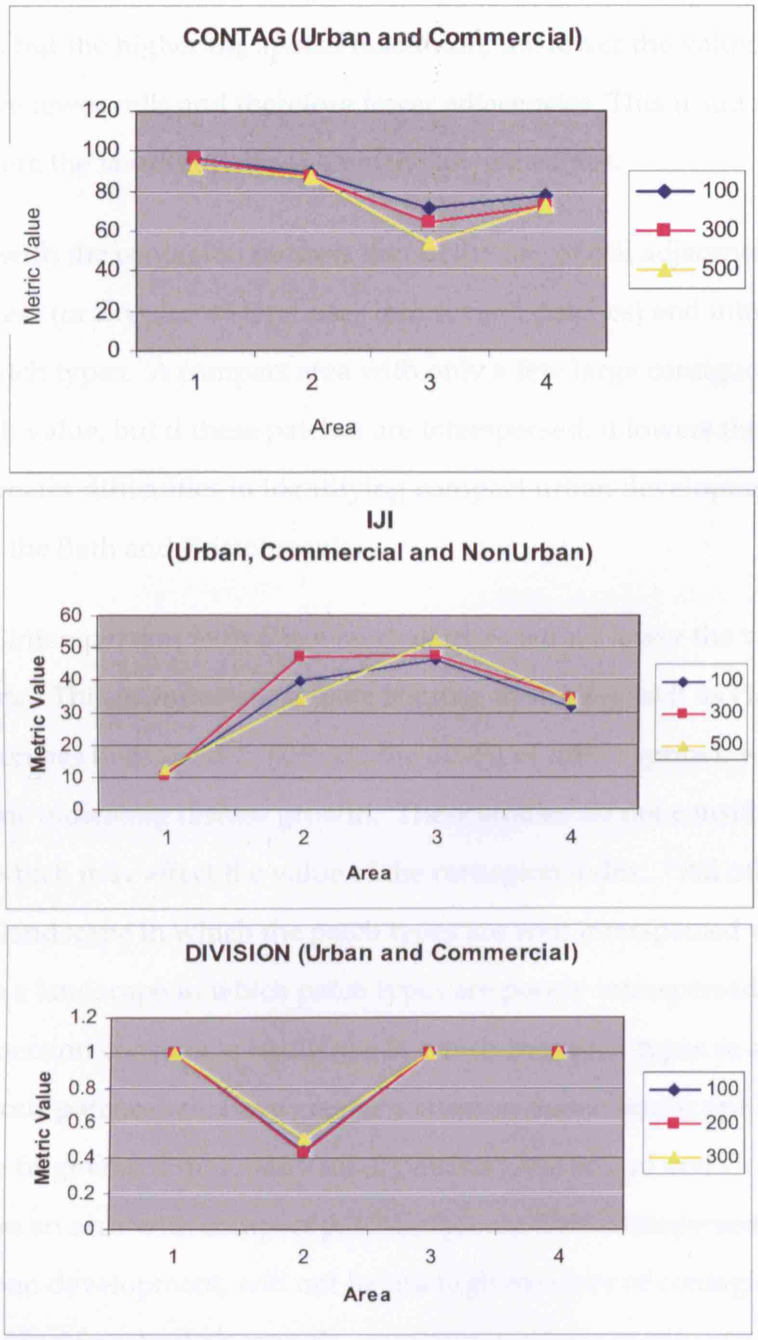
Figure 7.33: Results for Edge Density, Patch Size Standard Deviation (Area SD) , Mean Nearest Neighbour Distance (ENN_MN) (resolution 1 is 100m, 2 is 300m and 3 is 500m)

In this case, Bristol has the largest standard deviation, with an average area_SD of 3163, together with large patch sizes, which is due to the single large urban centre, existing alongside several small sliver patches. The other three districts have lower standard deviations, with Bath and North East Somerset with an average area_SD of 385, having a slightly larger standard deviation than South Gloucestershire and North Somerset (with area_SDs of 344 and 205 respectively). The measure has differentiated between Bath and North East Somerset which contains the fairly compact but small city of Bath, although patch size as represented by the percentage of land area and largest patch index does not show any distinction.

For mean nearest neighbour distance (ENN_MN), in Figure 7.33, shows Bristol as having the lowest value of 639 m indicating that it is the most compact with the shortest distances between patches. North Somerset has the second lowest value at 1011 m, followed by South Gloucestershire at 1552 m, and Bath and North East Somerset at 1540 m. This metric does not take account of the size or density of patches so although it indicates the extent of the scatter of land use in the landscape, used in isolation it does not provide an adequate measure of sprawl.

The contagion, interspersion and juxtaposition and division metrics are all landscape level metrics which are heavily influenced by the classes included in the analysis. In this case the non urban class was excluded as it represents the 'background' of the matrix and therefore distorts the assessments of the classes of interest, although the interspersion and juxtaposition metric is calculated with the inclusion of the non urban land use class.

The contagion metric in Figure 7.34, results in Bath having 95 percent contagion - the highest value of contagion - followed by Bristol with 88 percent, North Somerset with 74 percent, and South Gloucestershire having the least compact urban development with 63 percent. Although Bristol has the most contiguous development, it scores slightly lower than Bath on the contagion measure. This is due to Bath having an urban area represented by a large patch with relatively few smaller patches, and the metric is confounded by the number of small sliver patches in the Bristol area which gives it a lower value.



Area 1 Bath and North East Somerset, Area 2 Bristol, Area 3 South Gloucestershire, Area 4 North Somerset.

Figure 7.34: Results for measures of Contagion, Interspersion and Division

The metric also counts cell adjacencies between patch types, not patch adjacencies, which results in high values for large compact areas. An urban area surrounded by large areas of non urban land would also result in a high score on the contagion metric, as in the case of Bath. There is little difference between the three resolutions of 100, 300 and 500m cells, but the higher the spatial resolution, the lower the value, as larger resolutions have fewer cells and therefore fewer adjacencies. This result is seen in Figure 7.34 where the largest cell sizes have the lowest values.

One difficulty with the contagion index is that in the use of cell adjacencies, it measures both compactness (or division of land uses into several patches) and interspersion of land uses or patch types. A compact area with only a few large contiguous patches will have a high value, but if these patches are interspersed, it lowers the contagion value, which creates difficulties in identifying compact urban development as highlighted by the Bath and Bristol results.

A high level of interspersion with a few large patches would lower the value of the contagion metric. This is important to note because in studies such as Herold et al. (2003), contagion has been used to indicate the extent of urban sprawl, with a low contagion metric indicating diffuse growth. These studies do not consider variations in interspersion which may affect the value of the contagion index. "All other things being equal, a landscape in which the patch types are well interspersed will have lower contagion than a landscape in which patch types are poorly interspersed. ...thus holding interspersion constant, a landscape in which the patch types re aggregated into larger, contiguous patches will have greater contagion than a landscape in which the patch types are fragmented into many small patches" McGarigal and Douglas (1995, p.52). Therefore an area with compact patches that are well interspersed as occurs with polycentric urban development, will not have a high measure of contagion but is still representative of compact urban growth.

The interspersion and division metrics , as in Figure 7.34, separate the measure of compactness and interspersion. The interspersion metric is more suited to the identification of urban sprawl as it measures patch adjacencies rather than cell adjacencies. A low value reflects a high level of intermixing of patch types, while a high value indicates little intermixing of patches. Bath and North East Somerset has the lowest value with an IJI of 11 percent, followed by North Somerset at 33 percent, with Bristol and South Gloucestershire having similar values, at 40 percent and 49 percent respectively. This result is consistent with the single large compact area of the Bristol region, and shows less intermixing in the South Gloucestershire region.

The division metric, in Figure 7.34, measures the division of the land use class into number of patches and as such measures the scatter of urban development. Bristol has the lowest value with an average of 0.46, South Gloucestershire 0.99, Bath and North East Somerset 0.99, and North Somerset 0.99 indicative of its large single patch. The level of division for the other three areas is much higher, but is similar for all three.

7.6.1 Summary Landscape Measures

Landscape ecology metrics can be used to identify and quantify patterns of urban sprawl. These types of metrics have the potential to identify whether development is occurring in a sustainable, compact fashion or leading to fragmented and scattered growth. However, the measures have difficulty in identifying more complicated morphological patterns such as the polycentric landscape, where there is a combination of a few large patches and several small patches, as in Bath and North East Somerset. The measures selected while able to distinguish the more urbanized morphology of the Bristol area have not been able to distinguish between Bath and North East Somerset, South Gloucestershire and North Somerset despite the difference in the nature of sprawl in these areas.

This is largely a result of the measures considering the urban morphology in terms of land use area, in isolation from attribute values such as population or employment density, which would identify small but high density urban centres. The measures provide a more accurate description where there are extremes such as the Bristol area with a single large patch, or where the distribution of patch sizes is more even. It is clear that the measures cannot be viewed in isolation if an accurate picture is to emerge. One area for further investigation lies in identifying a typology of sustainable land use patterns using techniques such as factor analysis to determine which metrics are associated most closely with others and to develop indices that combine the most relevant measures.

Another difficulty lies in selecting the area for analysis. These measures are heavily dependent on the boundary of the study areas and reflect morphological patterns only. For example, the functional connection between Bristol and South Gloucestershire is not indicated by these metrics. Further work experimenting with the boundaries of the study area would be useful, and would make use of connectivity between areas, in terms of commuting data. Nevertheless, these metrics are clearly suitable for sub national indicators and thus suitable for quantifying patterns at the city wide or regional scale.

The approach outlined in this study has taken a step in this direction bringing a new perspective to the development of indicators for environmental sustainability. When applied over time, these metrics are useful for examining the process of development, which is particularly useful at the peri urban interface – an area of intense pressure for change and competition for land use. This study provides evidence that landscape metrics can provide an appropriate basis for research in urban sustainability, and examines methods which are useful for regional level planning and development.

Chapter 8

Conclusions

The thesis extends the work of the SCATTER project which examined the definition of sprawl in a European context, the characteristics of sprawl and the means of identifying sprawl using quantitative measures. Urban sprawl is a term typically used with reference to the US urban context, to refer to urban development characterized by rapid, uncontrolled growth in rural and undeveloped areas, with wide separation of uses, and uniform low density housing divorced from services and retail development.

Existing definitions are based on urban form, urban land use and the impacts of sprawl. However, past studies measuring sprawl have used differing definitions of the phenomenon, with little agreement on how to operationalise the measurement of sprawl. A variety of urban forms have been covered by this umbrella term, with inconsistencies arising as sprawl is both country and time specific, and secondly, as sprawl is a normative concept, set against the policy and planning goals for cities.

The confusion stems in part from the use of a variety of definitions, the application of measures to inconsistent geographic and administrative areas, and disagreement on the level of density applicable to the term urban sprawl. Definitions of urban sprawl have typically focused on the local area, as this term has been rooted in the US experience, where interest in urban sprawl and its impacts lies at the neighbourhood and individual level. Past research has assumed a monocentric urban form, with studies focusing on the urban area. However, studies of sustainable settlement patterns show that it is important to view this in the context of the wider metropolitan or regional scale.

Previous measures have been applied to the US urban form, and given the differing nature of urban morphology and density in Europe where sprawl has different outcomes and urban effects, work is needed to understand the extent to which these measures identify sprawl in Europe. The thesis has examined the suitability of measures developed in the North American context for interpretation of urban sprawl with European densities and spatial scales.

The findings are based on the analysis of sprawl undertaken by the SCATTER project together with analysis of further measures of sprawl (based on aggregate density measures, measures which examine interactions of concentration and density and measures based on land use patterns) which examine the impact of the scale of the study area on the identification and understanding of sprawl and the application of these measures to a polycentric urban form.

The SCATTER project revealed a picture of urban sprawl as a mixture of urban typologies and characteristics. The definition of urban sprawl as derived from the interviews cannot be tied to any particular typology and the case cities exhibit common features across a variety of urban forms. For instance, the case cities present certain commonalities in that increasing numbers of young families locate in suburban residential developments not necessarily out of choice, but often driven by considerations of space and affordability, yet despite this the city centres remain relatively strong, both as economic centres and as desirable residential locations.

The patterns of sprawl presented by the quantitative measures used in the SCATTER project likewise reveal a complex interplay of densities and growth patterns. This variety of patterns of sprawl also applies to the concentration and spread of development across the case study regions. Processes associated with urban sprawl are present even with only moderate growth rates in the case cities. There is a consistent pattern of high density and also stable or increasing growth rates for both population and employment in the urban centres but the problems associated with sprawl occur even without a decline in density to the hinterland – typical of urban sprawl in North America.

The causes of sprawl are also unlike expressions of sprawl in the literature in that although consisting of private sector development, urban sprawl is often a result of planning initiatives. For example, uncoordinated growth and sprawl due to the different agendas of neighbouring local authorities is a repeat occurrence. The negative impacts, particularly in the case of Bristol, relate not so much to the low density of development nor to the physical form but to the spread of development across administrative boundaries. In this sense sprawl is part of urban growth and its impacts are tied to broader societal changes, unrelated to urban form, such as increased car use.

The measures used in the SCATTER project only partially express this picture of sprawl in that they do not combine information on population and employment density with patterns of spread or concentration. There is also distortion in the level of sprawl identified where a more polycentric urban pattern is present, as the measures are based on moncentric zones around a central city focus. This is particularly the case in Bristol and Brussels. Additionally, local variation in the pattern of sprawl is not indicated by the aggregate measures used which are based on the study region as a whole or based on each zone as a whole.

There is a wide variation in the effectiveness of the policies to combat sprawl in the three case cities of Brussels, Helsinki and Stuttgart. There are particular discrepancies in the effectiveness of the ABC policy and the transport policies; namely, the increase of car use costs, the cordon pricing, and the decrease in the public transport fare. The ABC policy is much more effective in concentrating development in the urban centre and urban zones and in increasing public transport use in Brussels than it is in the other two case cities. The transport policies of increased car use costs and cordon pricing are much more effective in controlling travel times, car mileage, home to work travel distance and increasing public transport share in Helsinki. The impact of all policies tested is only moderate in Stuttgart.

This variation in policy effectiveness further illustrates the complex nature of urban sprawl. Helsinki with its large hinterland and concentration of growth in the urban centre and the outer urban ring is more responsive to transport policies. Brussels and Stuttgart, despite having similar densities and a spread of development across the study region do not show a similar response to the urban policies, with Brussels showing larger variations, with land use policies being particularly effective.

Urban sprawl is multi faceted not only in its pattern of development but also in the consequences of sprawl and the effective measures to tackle sprawl in Europe. This is contrary to the idea of sprawl as a single pattern of urban development to which one common definition can be applied. Urban sprawl is much more complex, and although elements and consequences of sprawl are repeated, this is overlain by the specific patterns of urban growth, which do not necessarily match forms traditionally associated with urban sprawl. It is evident that this growth is inevitable, with the impacts of growth commonly attributed to urban sprawl occurring even in concentrated and compact urban areas.

These further measures of sprawl extend the analysis of the SCATTER project by observing the patterns of development at a more disaggregate level and using measures which combine the density of development and its concentration in the assessment of urban sprawl. The study of simple density measures has shown that differences exist based on the unit of study, and that this varies depending on the type of measure used. For the most part there is little difference between the functional and administrative areas, as the county and travel to work areas generate similar results. However, travel to work areas with wide ranging commuting patterns neighbouring highly dense conurbations have different results and inconsistent interpretations of urban sprawl. In addition, the district and urban areas cannot necessarily be substituted despite having similar densities.

Measures based on density, despite their popularity for identifying urban sprawl, are unable to identify the nature of sprawl in the European context. This is particularly the case where the urban form is polycentric, with existing patterns of localised low density urban growth in a region with otherwise high density pockets of development. This indicates that urban sprawl is too complex a phenomenon to be measured on the dimension of density alone. The measures of urban sprawl based on population and employment patterns show that the choice of area for the study of urban sprawl greatly influences the results. These measures are heavily dependent on the boundary of the study areas, and reflect morphological patterns only. For example, the functional connection between Bristol and South Gloucestershire is not indicated by these metrics.

The county and travel to work areas tend to have similar results for the measures, however, where there are travel to work connections to other major cities, this results in an inconsistent identification of sprawl, as seen with the measure of continuity. The district and urban areas also show similar results. However unlike the aggregate measures, differences are evident based on whether the district matches the urban area or is defined as a separate area.

The measures are also confounded by the high densities particularly when considering the one mile square area. The measures of continuity and concentration, show lower values for the urban and district areas, than for the travel to work and county areas, despite the latter having greater levels of sprawl. In this case, the measures are confounded by the high densities throughout the area, which results in an even spread of development due to the high density. This needs to be accounted for if these measures are to be used in the European context.

The measures of landscape ecology have difficulty in identifying more complicated morphological patterns such as a polycentric landscape, where there is a combination of a few large patches and several small patches as in Bath and North East Somerset. The measures selected have not been able to identify the smaller urban centre of Weston-super-Mare, nor the compact nature of the City of Bath. The measures selected while able to distinguish the more urbanized morphology of the Bristol area have not been able to distinguish between Bath and North East Somerset, South Gloucestershire and North Somerset despite the difference in the nature of sprawl in these areas.

This is largely because the measures consider urban morphology in isolation from attribute values such as population or employment density, which would identify small but high density urban centres. The measures provide a more accurate description where there are extremes such as the Bristol area with a single large patch, or where the distribution of patch sizes is more even. It is clear that the measures cannot be viewed in isolation if an accurate picture of urban sprawl is to emerge. Further work experimenting with the boundaries of the study area would be useful, and might also make use of connectivity between areas in terms of commuting data.

Previous attempts at measuring sprawl have assumed that sprawl is a phenomenon that can be measured consistently. The measures used have been applied across a variety of scales with little agreement on how this influences the identification of sprawl. Behind this is an assumption that sprawl is a specific land use pattern that can be identified at the most appropriate unit of analysis. Given that sprawl operates at a variety of scales, it is necessary to understand how the measures of sprawl are influenced by the unit of analysis.

The research has identified that measures are sensitive to the spatial area used - even areas with some similarities, such as county and travel to work areas or district and urban areas do not produce consistent results. Additionally, previous studies include only areas adjacent to the urban core. However the nature of sprawl in Europe and its polycentric development includes far flung urban centres interspersed with rural areas which often have little to do with the urban centre. In Europe therefore, measuring sprawl is also complicated by the fact that self contained subcentres set in low density rural areas may contribute to sprawl in the city centre – as identified by the SCATTER project. Yet this is not identified by traditional measures of sprawl which assume that areas related to the urban centre are contiguous.

These findings highlight the difficulties inherent in defining and measuring sprawl, as sprawl is a complex phenomenon with experts in the regions often unable to agree on the patterns and consequences of this type of urban growth. It is not so much a specific land use pattern or set of patterns as a manifestation of concerns which are common features of modern urban growth - regardless of urban form - and which emerge from the emphasis of interpretation and the dimensions of interest to local administrators and land use authorities. The spatial scale at which urban sprawl is observed also heavily influences the identification of relevant issues and the selection and design of suitable indicators. In addition, the most appropriate scale is related to the question of institutional barriers and modes of cooperation between different institutional players – which defines the most appropriate scale for tackling sprawl.

This study fills a gap in the literature by examining the impacts of urban sprawl in Europe, and examining the application of measures of sprawl to polycentric urban landscapes - which differs substantively from the North American context within which sprawl is commonly placed. It also examines the statistical impact on measures of sprawl at different territorial scales and examines the impact of the functional area compared to the administrative area. It also considers the types of measures in conjunction which has not previously been considered and operationalizes the measure of diversity developed by Galster et al. (2001) which has not previously been applied to urban data.

A clearer understanding of urban sprawl is necessary to track the progress of policies combating sprawl, and clear definitions and methods of measuring sprawl are a step towards this. Policies tackling these negative impacts of sprawl typically call for compact cities which channel development to the city centre, and attempt to set physical limits to growth through growth boundaries and land preservation. Without a clear understanding of the characteristics, levels and patterns of sprawl, it is not possible to assess the necessity for these policies or evaluate their effectiveness.

In addition, the current literature, with its focus on the suburbs and peripheral extent of the major urban area is narrow in its geographical scope. The suburbs do not exist in isolation, but in the context of relationships with both the major urban area and the wider metropolitan region. The process of suburbanization is therefore part of the larger process of urban growth. This will set the stage for a less value laden interpretation of urban sprawl, one which places it in the context of urban growth as a whole.

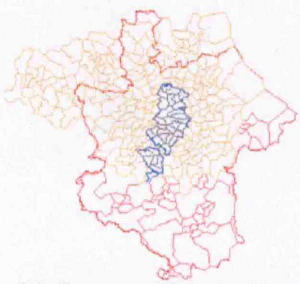
The literature has focused on providing definitions of urban sprawl, placing it as a unique urban form with specific characteristics and impacts. However, the results from the SCATTER project and from the extended work of the thesis identifying and measuring sprawl using quantitative indicators, has shown that the identification of sprawl is dependent on the type of measure and the scale to which it is applied. In addition, characteristics and impacts associated with sprawl are present regardless of urban form.

Future work would therefore more usefully focus on measuring the impact of general patterns of sprawl, rather than attempting to measure the urban form and quantify the precise degree of sprawl. For example, this could be explored using dynamic modelling of some of the less easily identifiable aspects of sprawl such as residential or income segregation, mixed uses and provision of services, contrasting an 'ideal' urban form such as the compact city with other sprawl forms, such as the polycentric city or the dispersed suburb. This would expand on the findings of the SCATTER project that despite the variation in form across the case cities, similar characteristics associated with sprawl were identified. It would also be useful to model the impact of policies to tackle sprawl on these more qualitative impacts – extending the focus of the SCATTER project on the impacts of sprawl on transportation. The modelling of fiscal policies to tackle sprawl, looking at the impact on costs associated with sprawl and the impact of such policies on the workings of the land and housing markets, would be of particular interest given that this type of policy is less widely used in the UK than land use based policies.

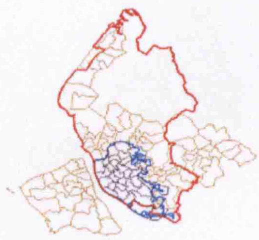
Given this similarity of impacts across a range of urban forms, it would also be useful to move discussions of sprawl away from the focus on urban form to examine the institutional and political conflicts between cities in a region, which result in impacts associated with sprawl, such as lack of public transport, separation of uses and the movement of the middle classes to the suburbs or neighbouring areas. Policy makers would thus benefit from examining sprawl at a wider regional scale, as opposed to the focus on the more limited urban scale, with a clearer focus on the actual outcomes of sprawl, rather than its definition and measurement.

Appendix A
Study Area Boundaries

The boundaries of the study areas are presented below. The areas are drawn at the same scale. Indicated are the county boundaries in yellow, the district boundaries in black, the travel to work boundaries in red and the urban boundaries in blue. The code used to identify the county in the 1991 Census is also provided.



03 Greater Manchester



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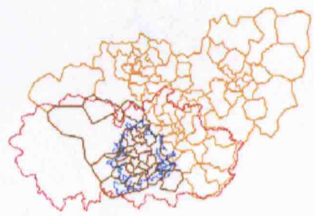
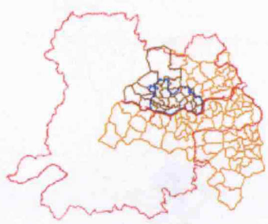
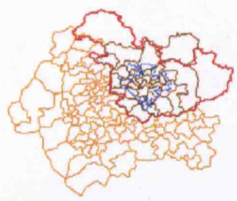


05 South Yorkshire

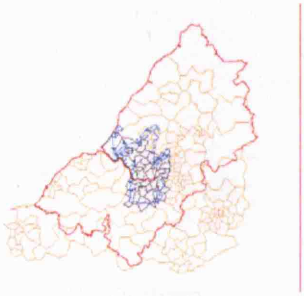


06 Tyne and Wear

07 West Midlands – data omitted from analysis

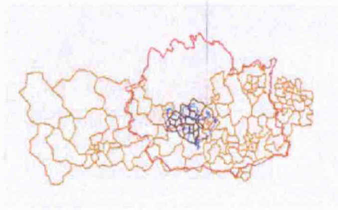


08 West Yorkshire



09 Avon

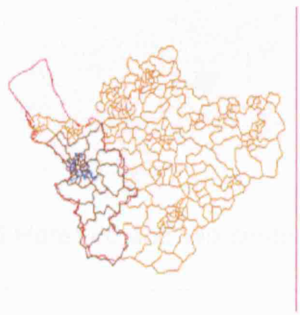
10 Bedfordshire



11 Berkshire

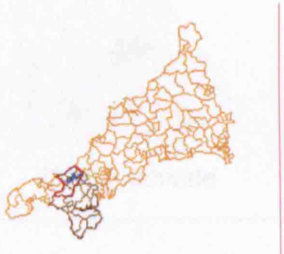
12 Buckinghamshire

13 Cambridgeshire

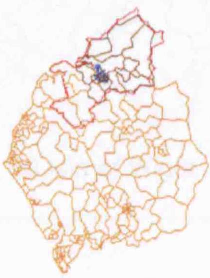


14 Cheshire

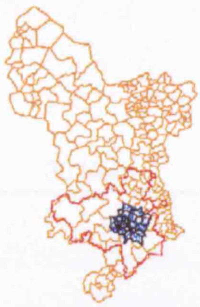
15 Cleveland



16 Cornwall and the Isles of Scilly

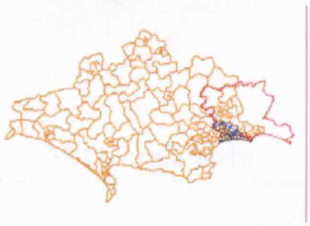


17 Cumbria

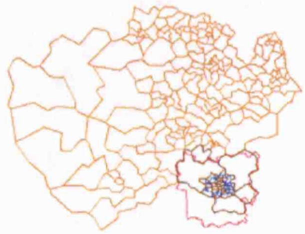


18 Derbyshire

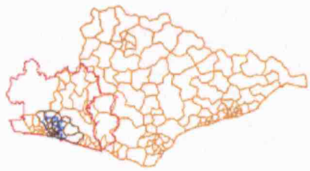
19 Devon



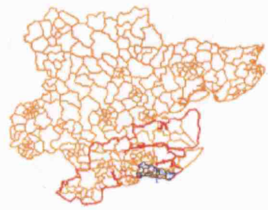
20 Dorset



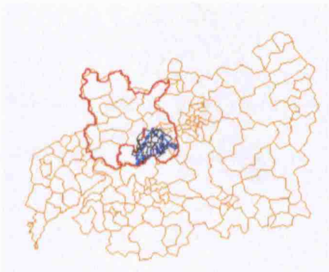
21 Durham



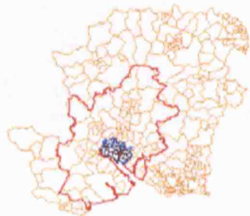
22 East Sussex



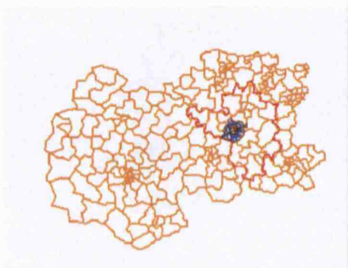
23 Essex



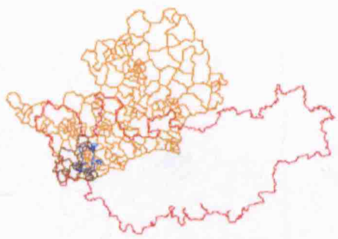
24 Gloucestershire



25 Hampshire

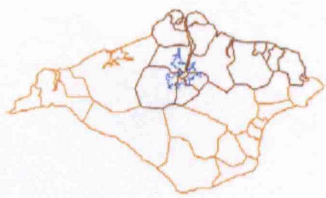


26 Hereford and Worcester

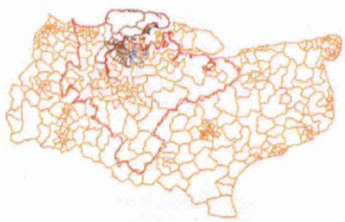


27 Hertfordshire

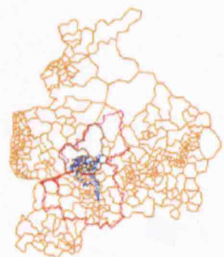
28 Humberside



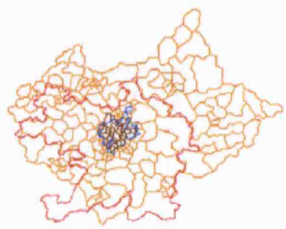
29 Isle of Wight



30 Kent



31 Lancashire



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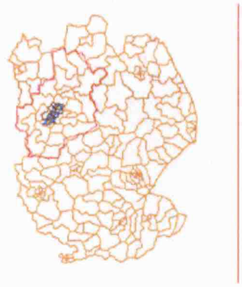
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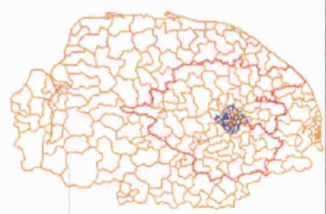
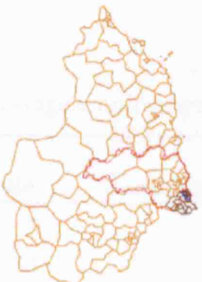
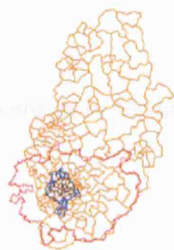
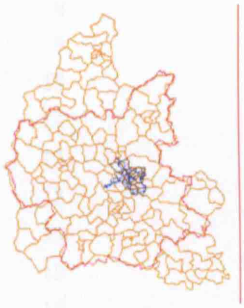

34 Norfolk

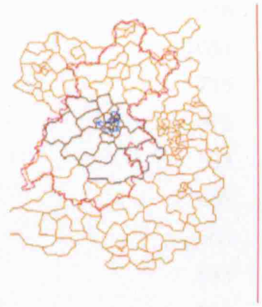

35 Northamptonshire


36 Northumberland


37 North Yorkshire


38 Nottinghamshire


39 Oxfordshire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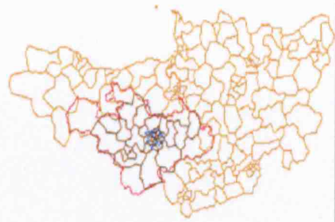
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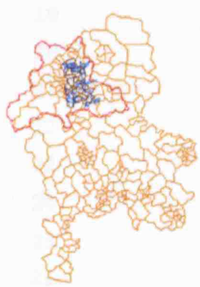
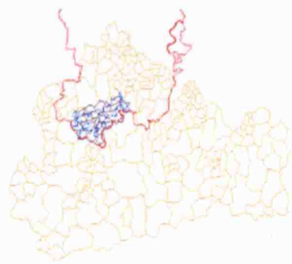

42 Staffordshire


43 Suffolk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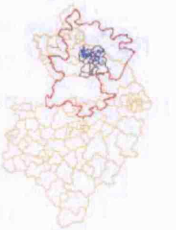
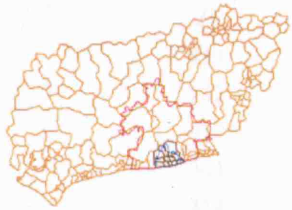


45 Warwickshire



46 West Sussex

47 Wiltshire

Regional average employment densities used to define the employment subcentres in section 7.2

county code	density/acre	density/km (conversion)
3	5	1200
4	5	1189
5	3	818
6	5	1265
7		
8	4	918
9	4	1054
10	3	715
11	4	971
12	2	533
13	2	468
14	3	663
15	3	845
16	1	244
17	2	433
18	2	517
19	2	487
20	2	603
21	2	467
22	4	1066
23	2	543
24	2	446
25	3	751
26	2	371
27	3	796
28	3	629
29	3	712
30	3	701
31	3	842
32	3	699
33	1	323

34	2	404
35	2	576
36	1	308
37	2	419
38	3	732
39	2	457
40	1	344
41	2	414
42	2	600
43	2	454
44	3	649
45	2	465
46	3	743
47	2	601

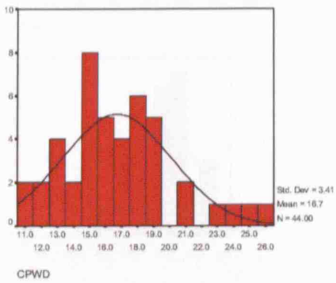
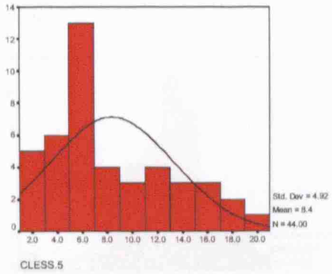
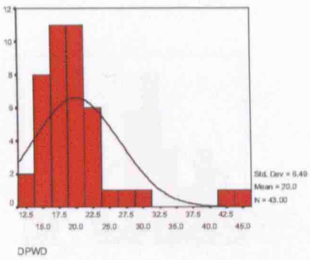
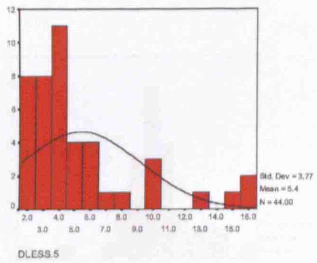
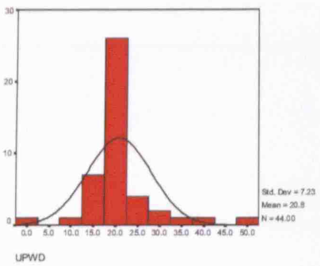
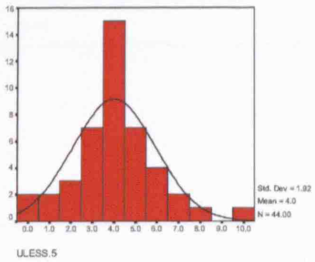
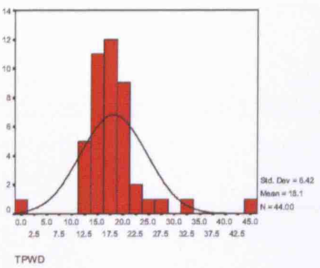
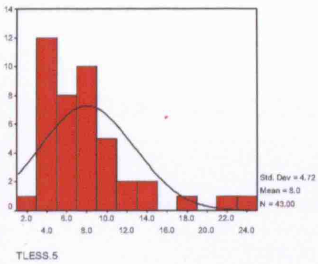
Appendix B

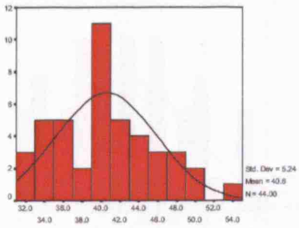
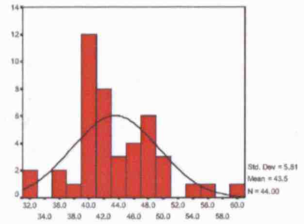
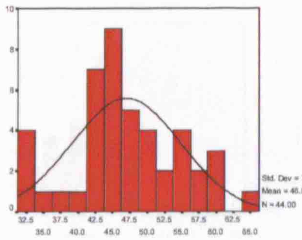
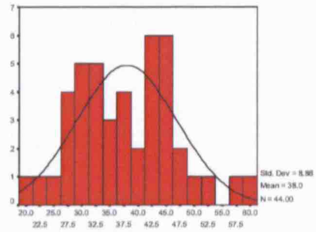
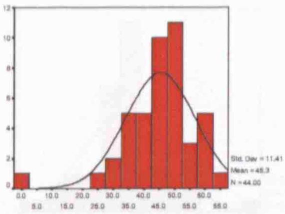
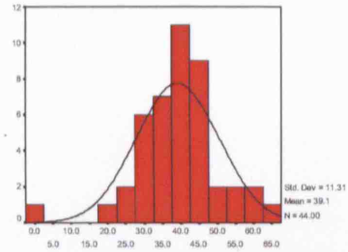
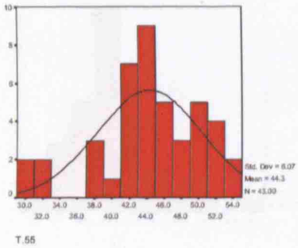
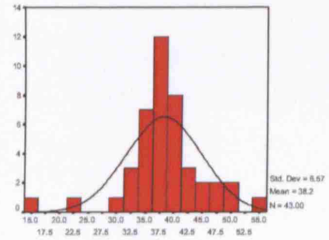
F Test Assumptions

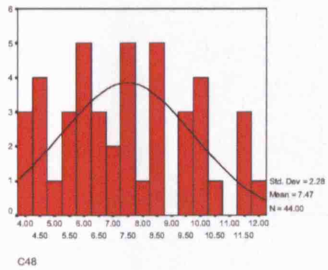
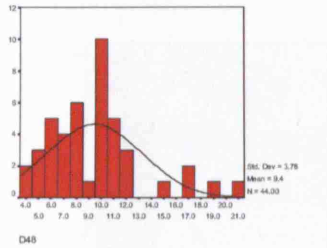
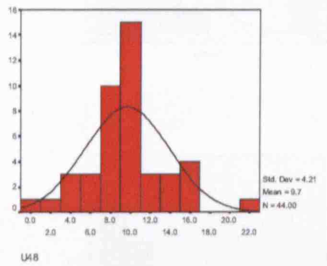
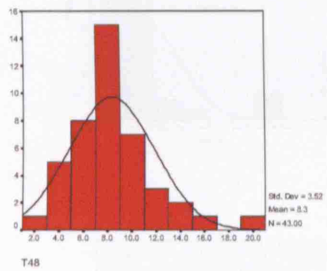
This section presents the supporting material used to assess whether the assumptions of normality and homoskedasticity of the F tests detailed in section 7.2 are satisified

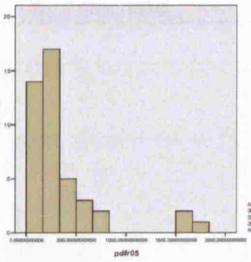
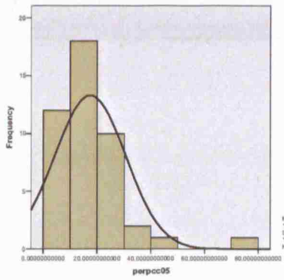
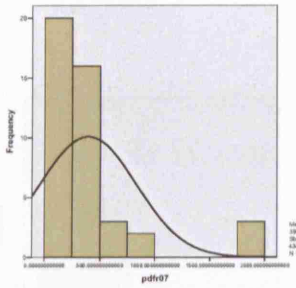
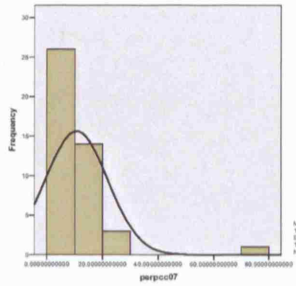
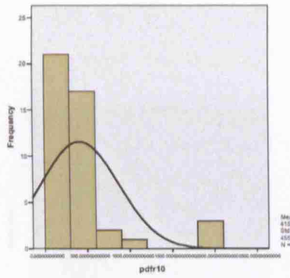
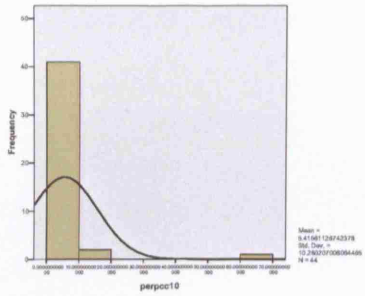
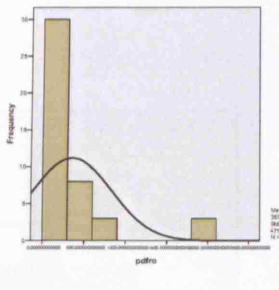
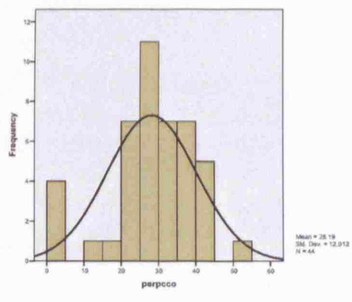
Histograms of Measures

The histograms provide a visual indication of whether the data is normally distributed. The histograms for each measure and for each of the four scales for that measure are presented.

	pwd	less 0.5
county		
district		
urban		
ttw		

	0.5-5.0	5.0 - 48
county	 C5.148	 C.55
district	 D.55	 D5.148
urban	 U.55	 U5.148
ttw	 T.55	 T5.148

	>48	
county		
district		
urban		
ttw		

	pdfr	perpcc
05		
07		
10		
regional average		

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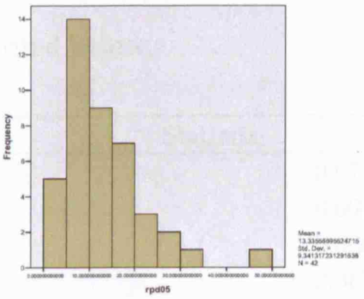
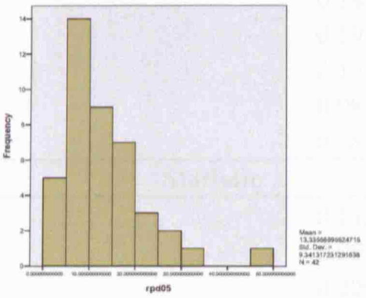
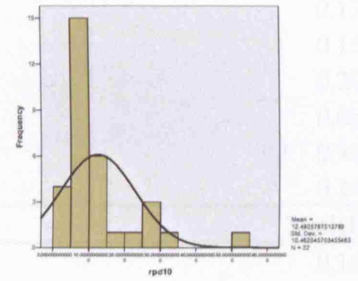
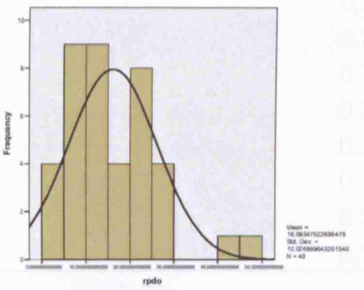
05	
07	
10	
regional average	

Kolmogorov-Smirnoff Tests for Normality

The Kolmogorov-Smirnoff Tests for Normality provides a statistical analysis of the normality of the data. The results of the normality of the test for each measure and scale are presented below.

COUNTY	Statistic	d.f.	Sig. 0.05
PHA	0.077	43	0.200
HHA	0.091	43	0.200
PWD	0.086	43	0.200
LDENSP*	0.365	43	0.000
MDENSP*	0.181	43	0.002
LDENSH*	0.416	43	0.000
MDENSH*	0.147	43	0.029
< 0.5*	0.195	43	0.000
0.5 - 5.0	0.123	43	0.098
5.1 - 48	0.083	43	0.200
>48	0.089	43	0.200

DISTRICT	Statistic	d.f.	Sig. 0.05
PHA	0.113	43	0.196
HHA	0.097	43	0.200
PWD*	0.229	43	0.000
LDENSP*	0.169	43	0.006
MDENSP*	0.164	43	0.009
LDENSH*	0.178	43	0.003
MDENSH	0.137	43	0.055
< 0.5*	0.204	43	0.000
0.5 - 5.0	0.086	43	0.200
5.1 - 48	0.102	43	0.200
>48*	0.140	43	0.034

URBAN	Statistic	d.f.	Sig. 0.05
PHA*	0.169	43	0.003
HHA*	0.152	43	0.014
PWD*	0.248	43	0.000
LDENSP*	0.206	43	0.000
MDENSP*	0.153	43	0.020
LDENSH*	0.175	43	0.004
MDENSH*	0.148	43	0.028
< 0.5*	0.150	43	0.016
0.5 - 5.0*	0.135	43	0.046
5.1 - 48	0.111	43	0.200
>48	0.132	43	0.057

TTW	Statistic	d.f.	Sig. 0.05
PHA*	0.141	43	0.032
HHA*	0.157	43	0.010
PWD*	0.224	43	0.000
LDENSP	0.127	43	0.104
MDENSP*	0.205	43	0.000
LDENSH*	0.407	43	0.000

COUNTY	Statistic	d.f.	Sig. 0.05
MDENSH*	0.217	43	0.000
< 0.5*	0.162	43	0.006
0.5 - 5.0*	0.144	43	0.025
5.1 - 48	0.132	43	0.059
>48*	0.140	43	0.034

employment centre at density 05	Statistic	d.f.	Sig. 0.05
pdcc05	0.124	43	0.200
pdfr05	0.188	43	0.009
perpcc05	0.250	43	0.000
perpfr05	0.250	43	0.000
rpd05	0.209	43	0.002

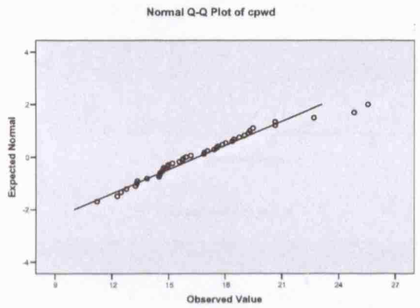
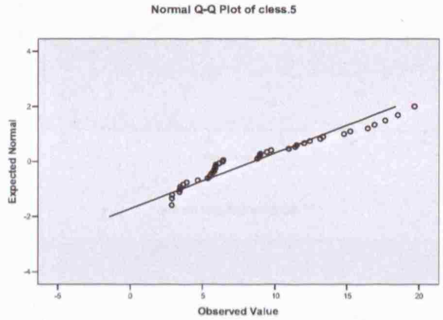
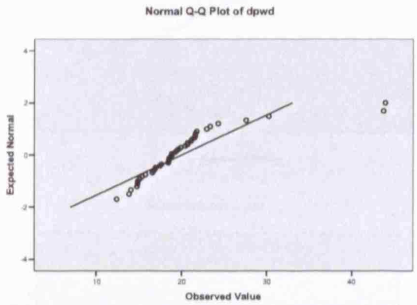
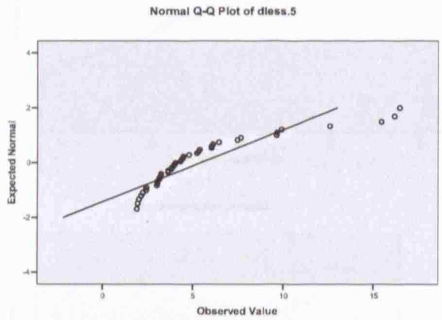
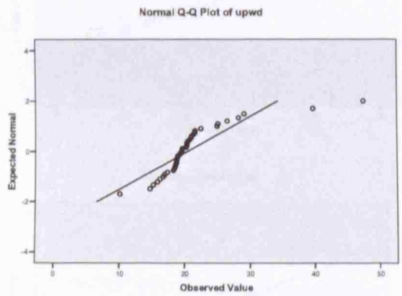
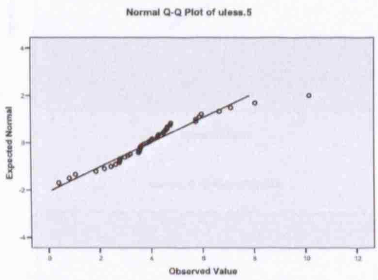
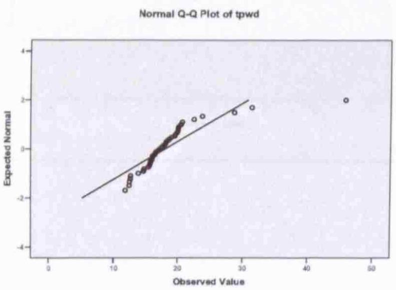
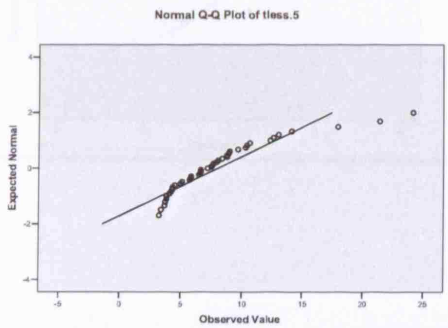
employment centres at density 07	Statistic	d.f.	Sig. 0.05
pdcc07	0.196	43	0.005
pdfr07	0.195	43	0.005
perpcc07	0.243	43	0.000
perpf07	0.243	43	0.000
rpd07	0.242	43	0.000

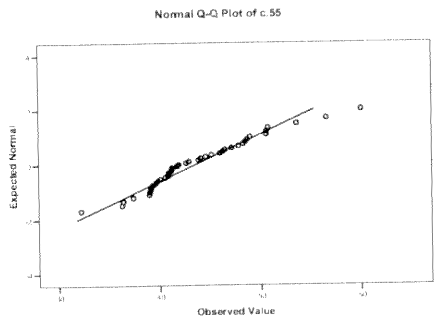
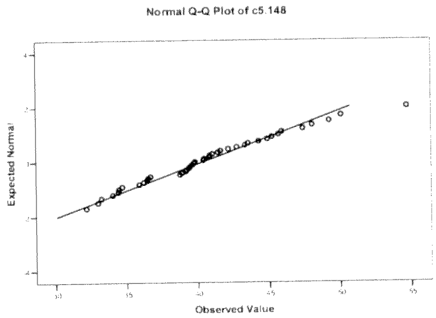
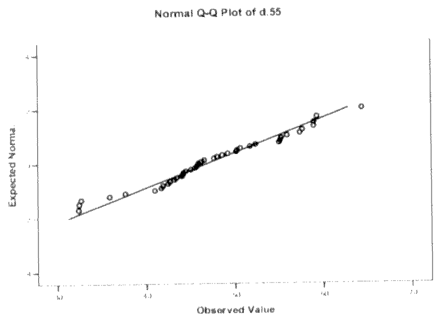
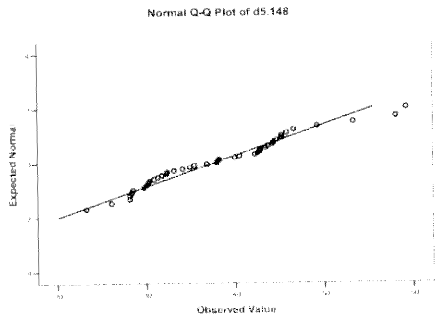
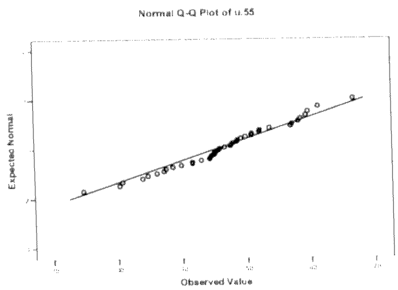
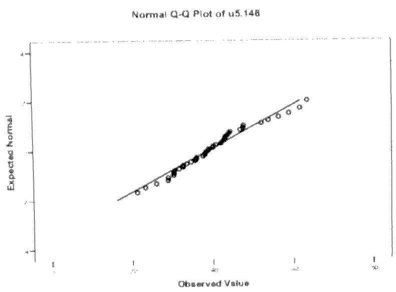
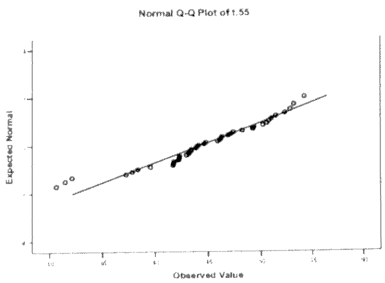
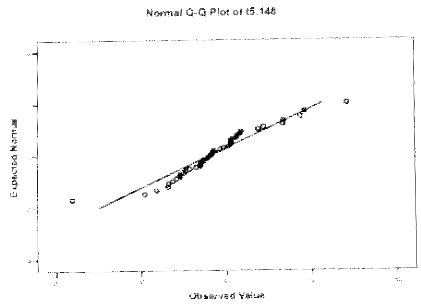
employment centres at density 10	Statistic	d.f.	Sig. 0.05
pdcc10	0.154	43	0.066
pdfr10	0.196	43	0.005
perpcc10	0.355	43	0.000
perpfr10	0.355	43	0.000
rpd10	0.214	43	0.001

Employment centres at regional average (Other)	Statistic	d.f.	Sig. 0.05
pdcco	0.162	43	0.042
pdfro	0.201	43	0.003
perpcco	0.167	43	0.032
perpfro	0.167	43	0.032
rpdo	0.182	43	0.012

Q-Q Plots Kolmogorov Smirnoff tests for normality

The expected value is plotted as a straight line, deviations of the data set away from that line represent a deviation from normality

Measure	pwd	< 0.5
county		
district		
urban		
		

	0.5-5.0	5.1-48
county		
district		
urban		
ttw		

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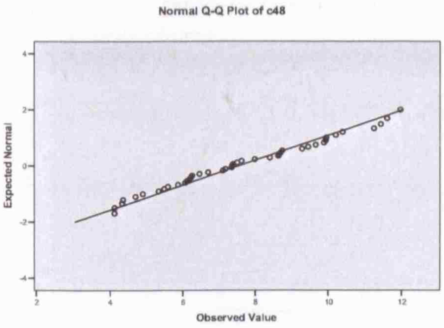
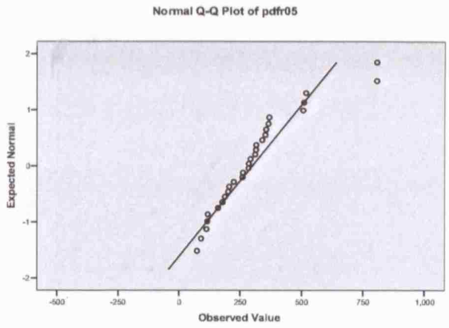
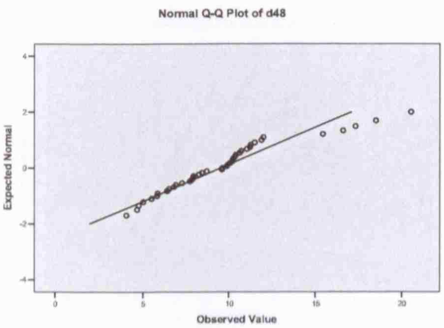
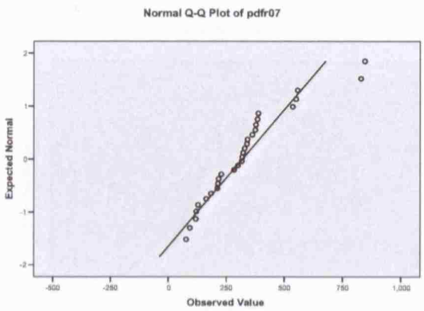
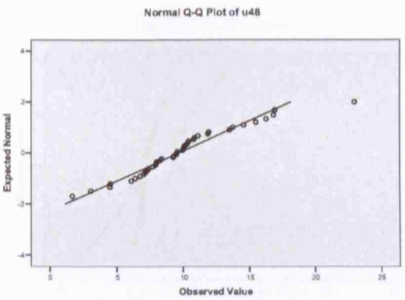
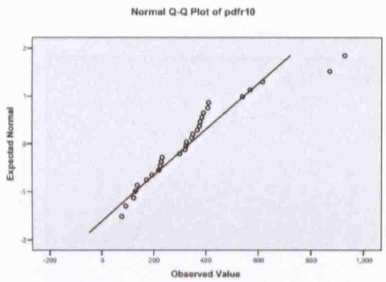
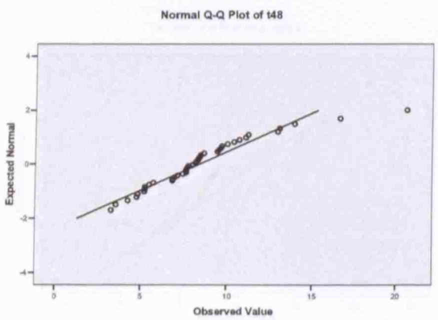
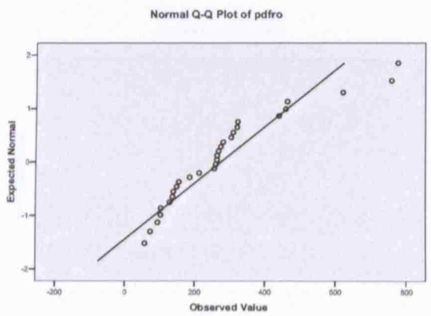
county		
district		
urban		
ttw		

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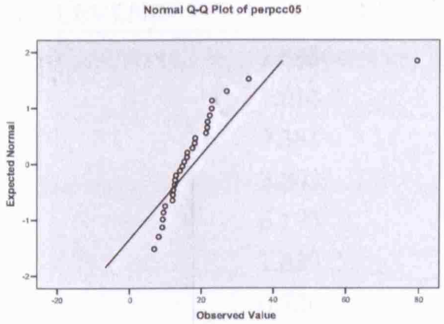
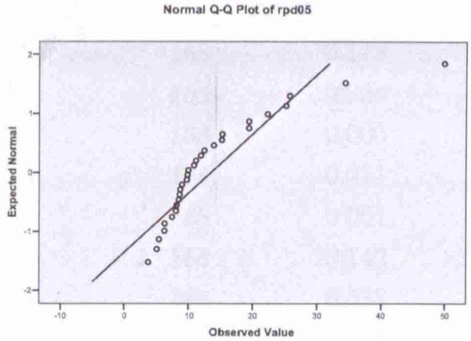
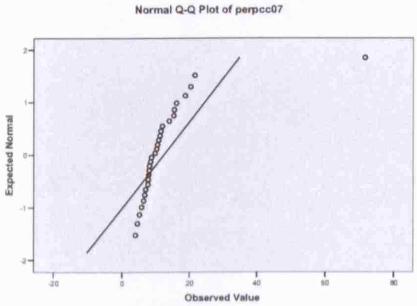
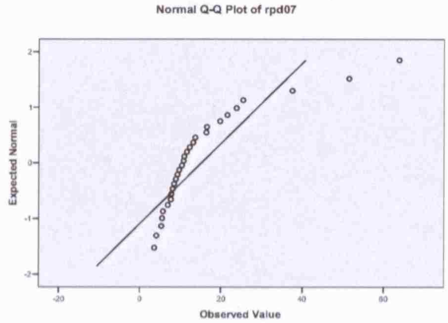
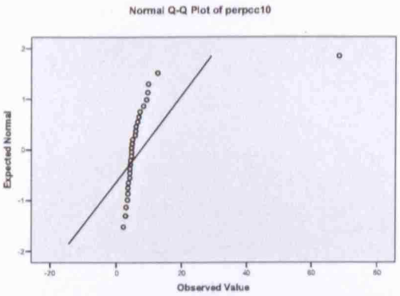
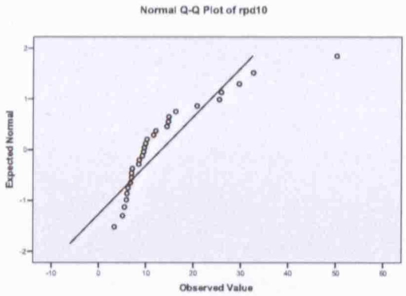
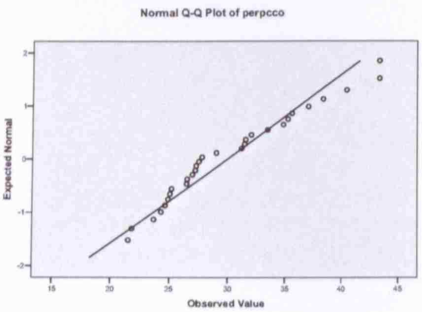
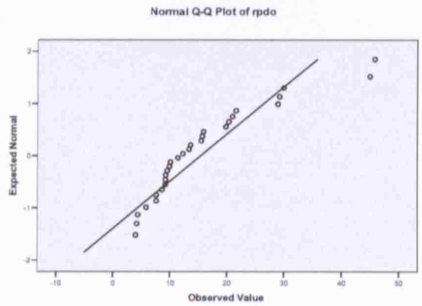
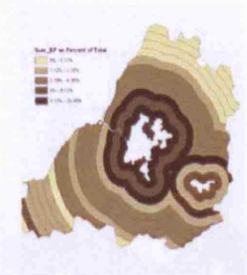
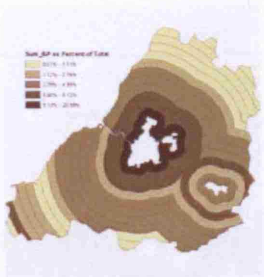
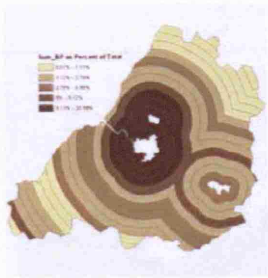
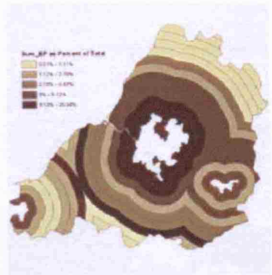
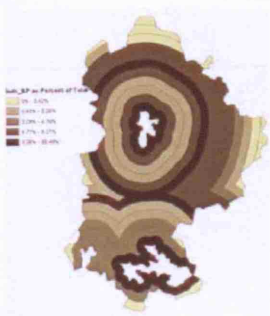
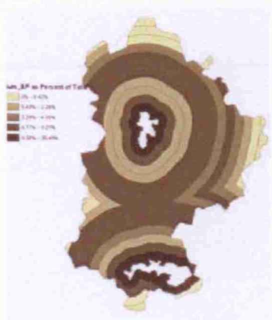
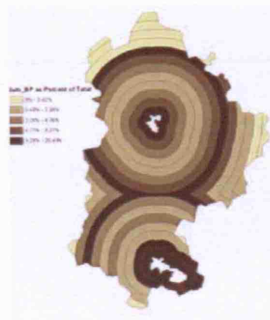
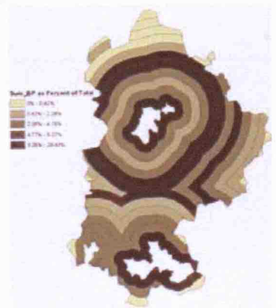
county		
district		
urban		
ttw		

Levene's Tests for Homogeneity

	LEVENE	d.f.	d.f.	Sig. 0.05
POP*	1.683	3	168	0.173
PWD	1.014	3	168	0.388
< 0.5*	9.381	3	168	0.000
0.5 - 5.0	3.803	3	168	0.011
5.1 - 48*	6.195	3	168	0.001
>48*	1.839	3	168	0.142
PDFR	0.726	3	168	0.538
RPD	0.665	3	168	0.574
PERCC	2.472	3	168	0.063

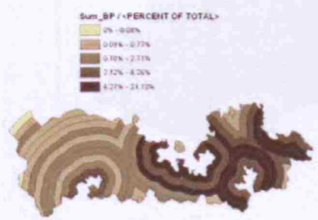
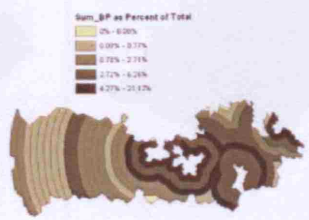
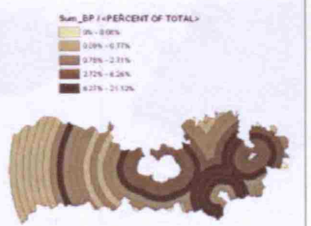
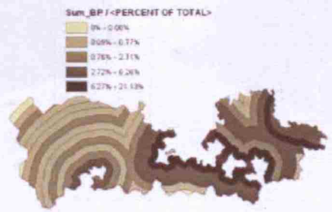
Appendix C: Measures of Centralization

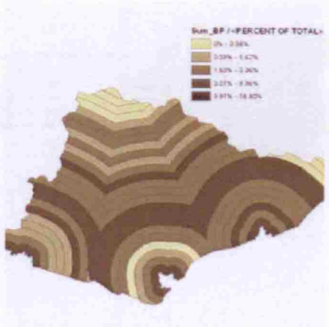
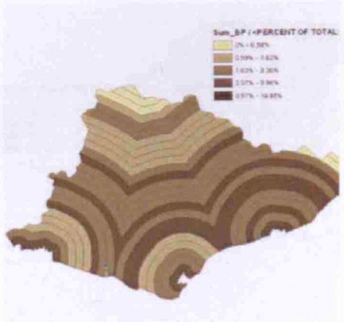
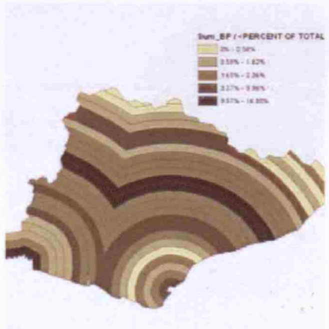
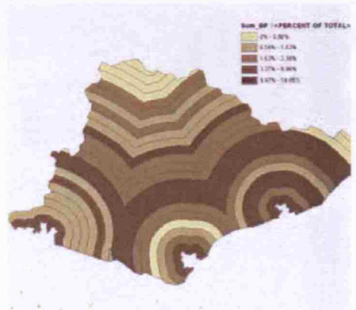
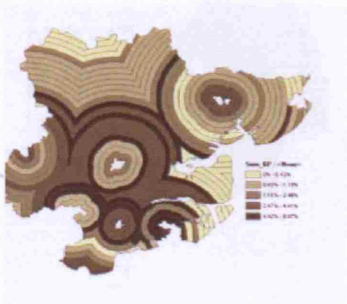
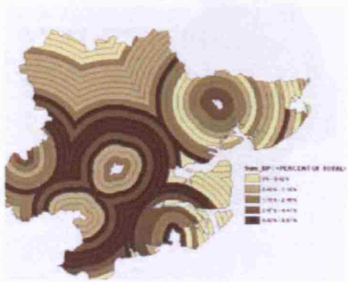
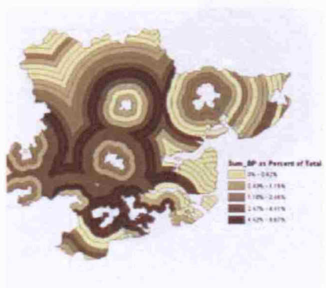
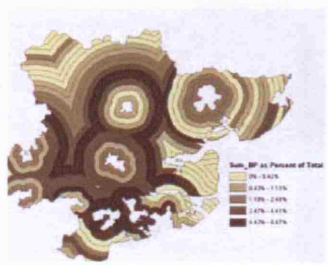
Measures of centralization: Residential (RP) and Business (BP) postcode totals for each concentric square mile

Area BP	Area BP	Area BP	Area BP	Area BP
09				
10				

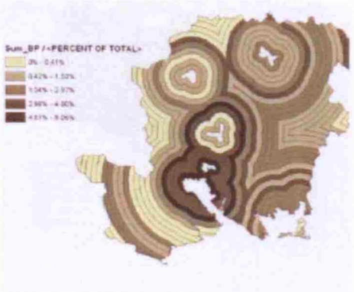
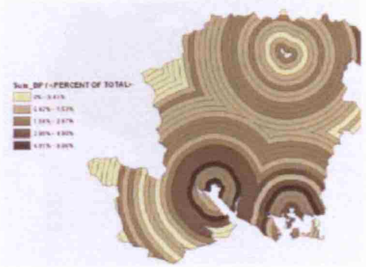
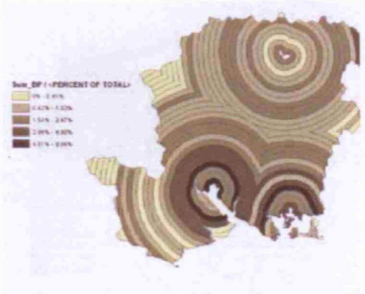
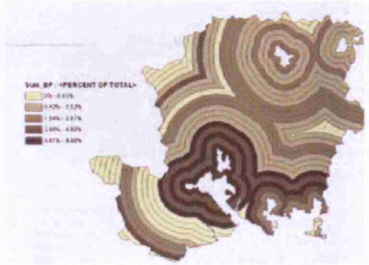
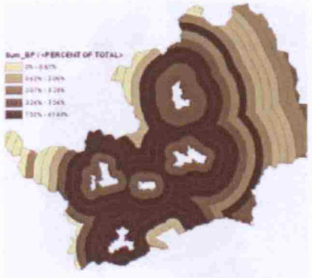
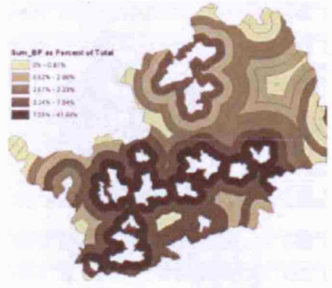
Appendix C: Measures of Centralization

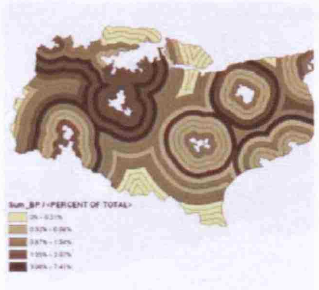
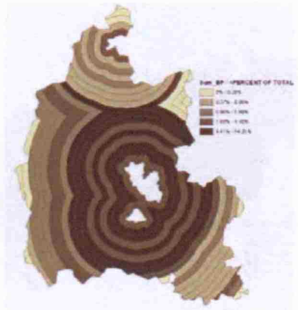
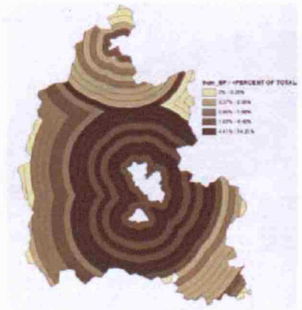
Measures of centralization: Residential (RP) and Business (BP) postcode totals for each concentric square mile

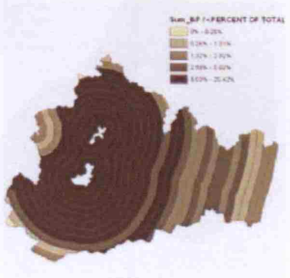
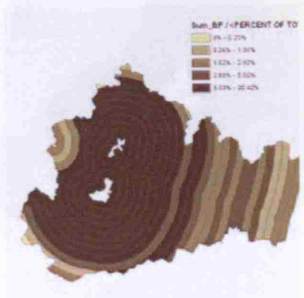
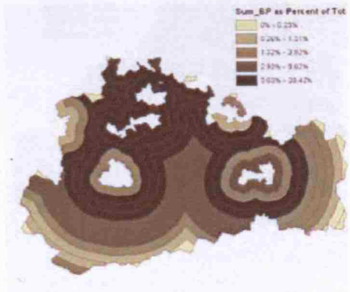
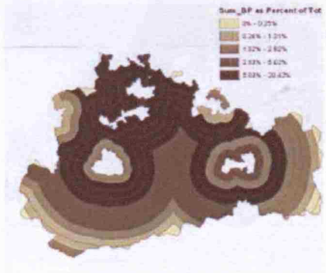
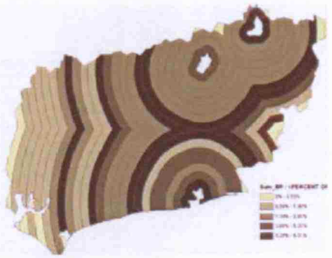
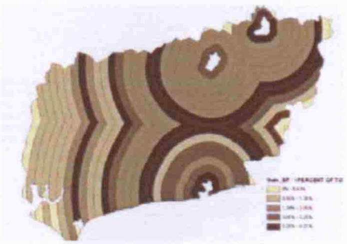
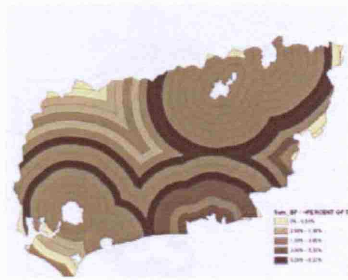
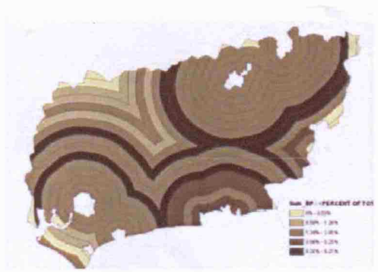
Area BP	Area BP	Area BP	Area BP	Area BP
11				

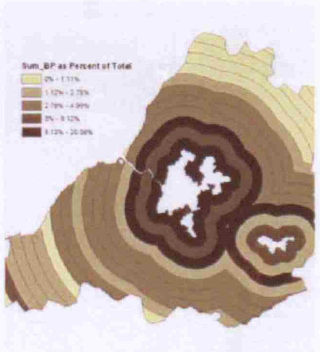
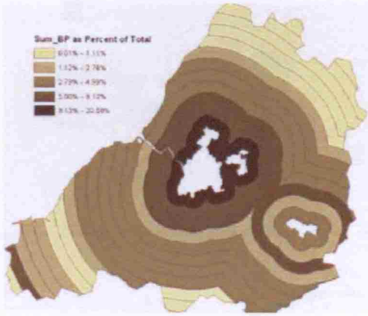
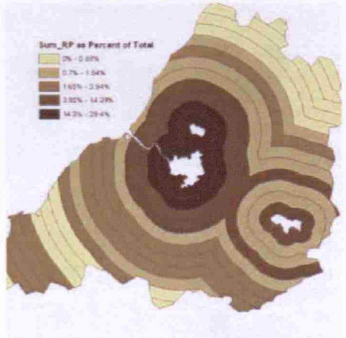
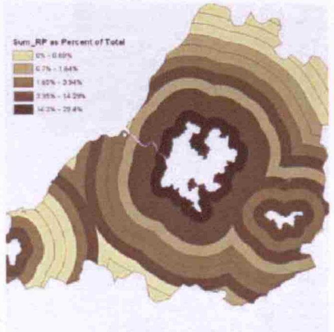
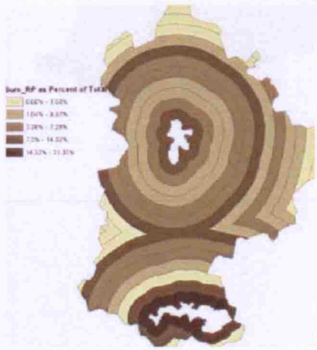
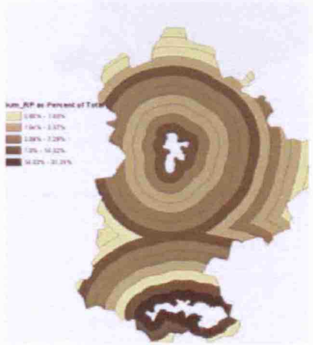
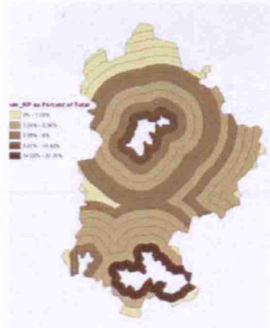
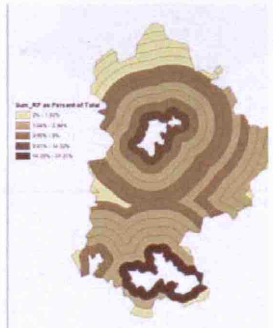
Measures of centralization: Residential (RP) and Business (BP) postcode totals for each concentric square mile				
Area BP	employment centre density 05	employment centre density 07	employment centre density10	Other – regional average employment centre density
22				
23				

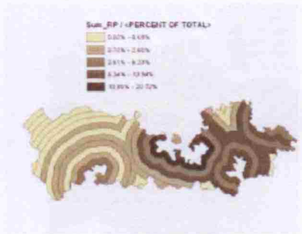
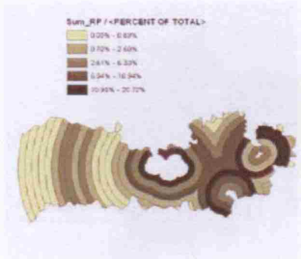
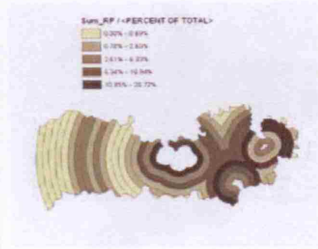
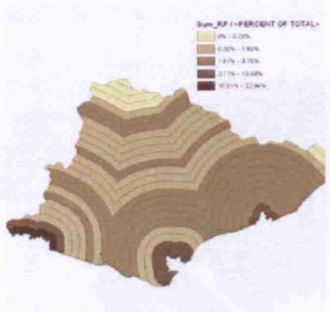
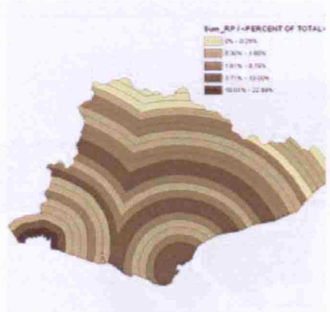
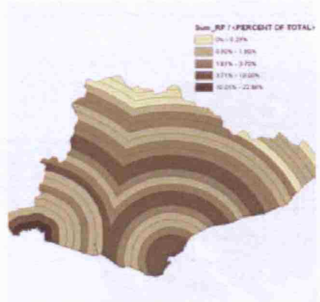
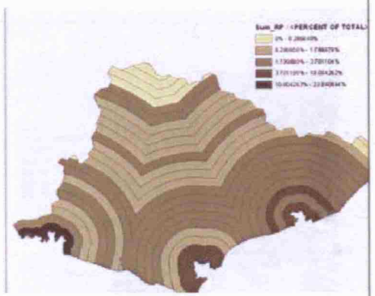
Measures of centralization: Residential (RP) and Business (BP) postcode totals for each concentric square mile

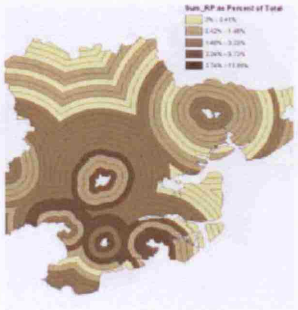
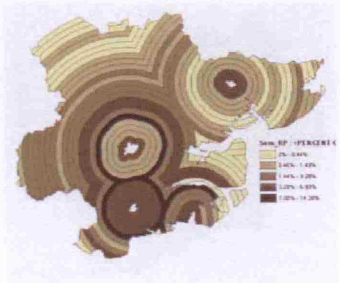
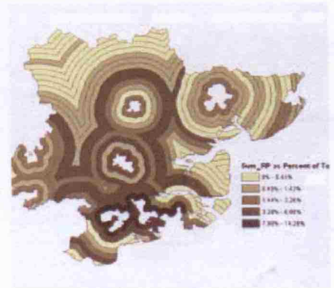
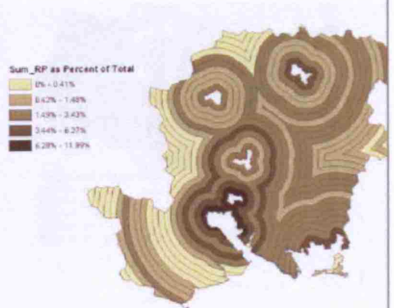
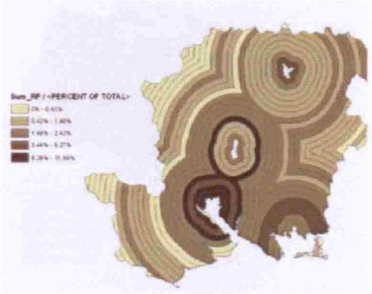
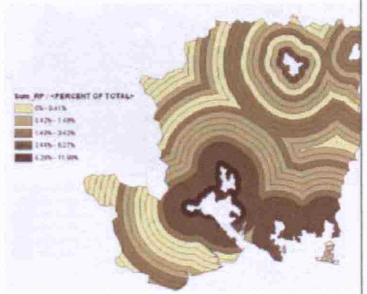
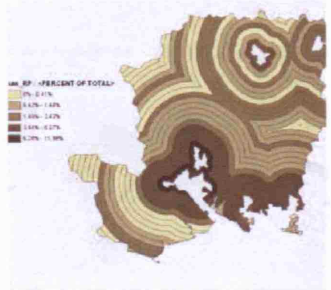
Area BP	employment centre density 05	employment centre density 07	employment centre density10	Other – regional average employment centre density
25				
27				

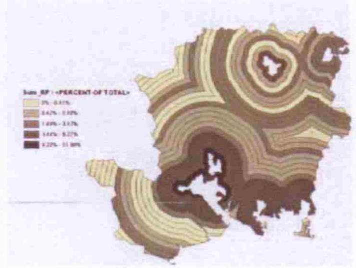
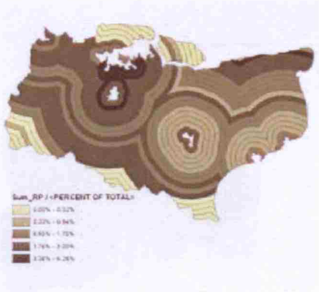
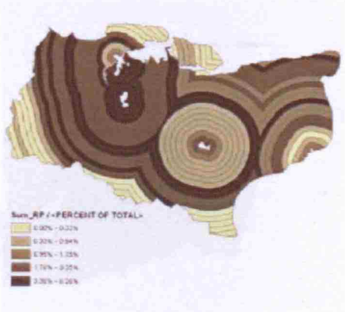
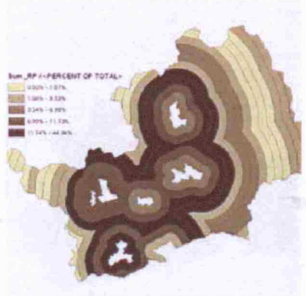
Measures of centralization: Residential (RP) and Business (BP) postcode totals for each concentric square mile				
Area BP	employment centre density 05	employment centre density 07	employment centre density10	Other – regional average employment centre density
30				
39				

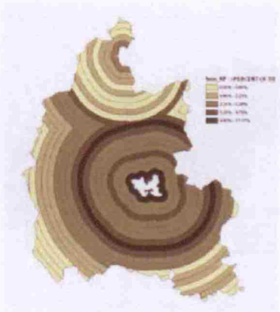
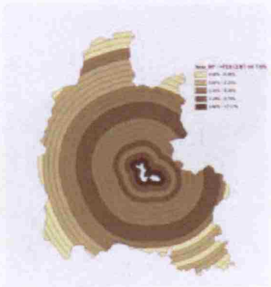
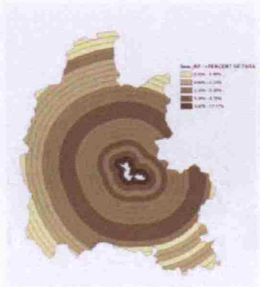
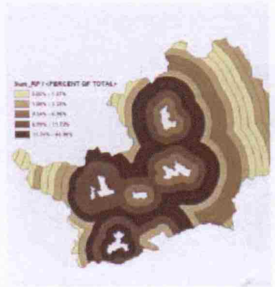
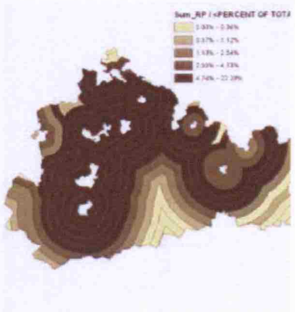
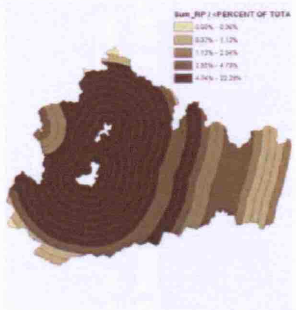
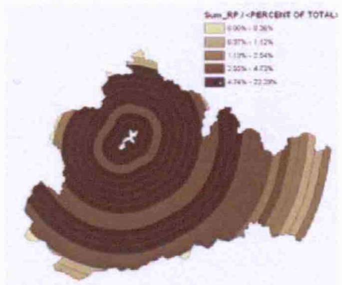
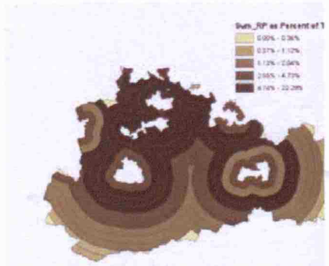
Measures of centralization: Residential (RP) and Business (BP) postcode totals for each concentric square mile				
Area BP	employment centre density 05	employment centre density 07	employment centre density10	Other – regional average employment centre density
44				
46				

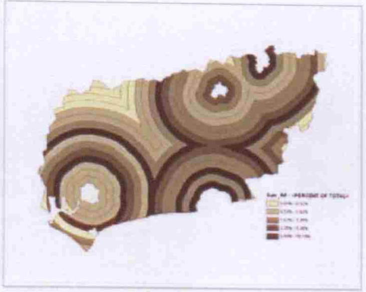
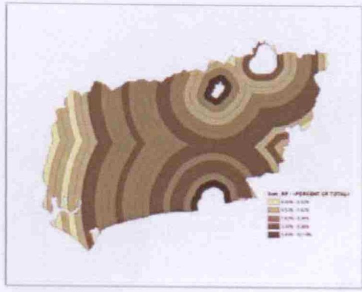
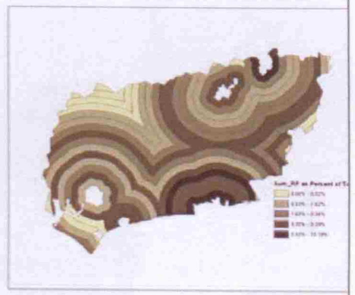
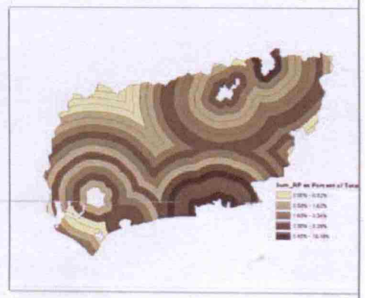
Area RP	05	07	10	Other
09				
10				

Area RP	05	07	10	Other
11				
22				

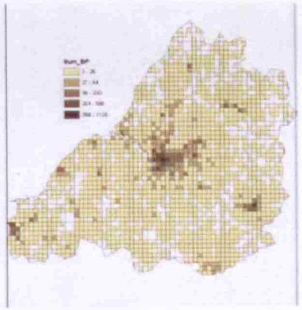
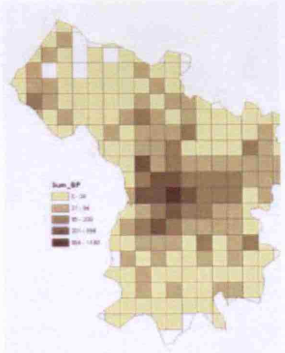
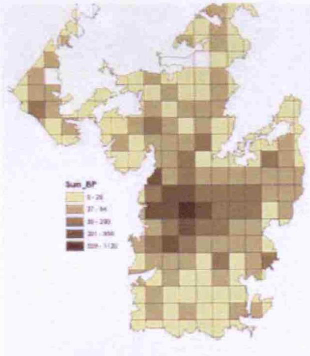
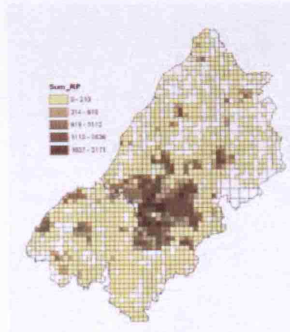
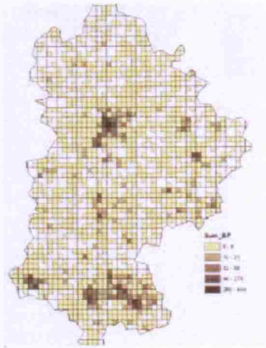
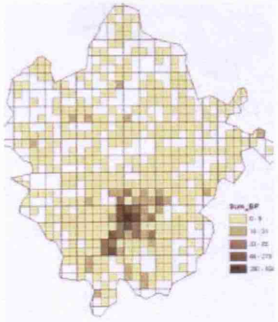
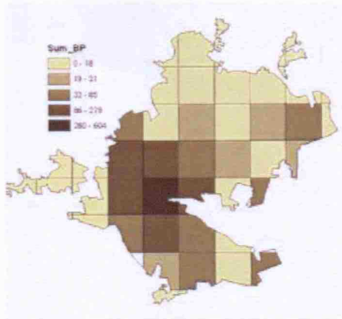
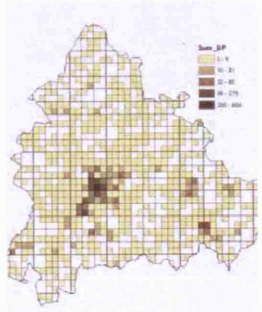
Area RP	05	07	10	Other
23				
25				

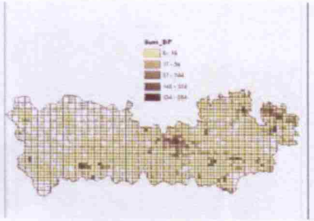
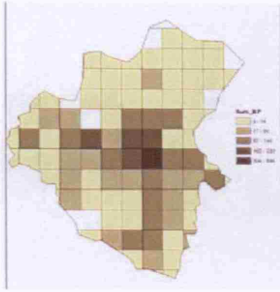
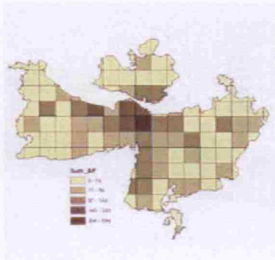
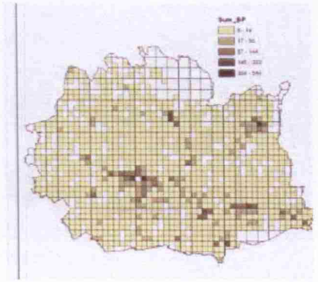
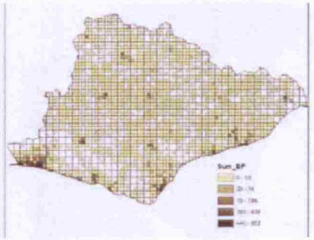
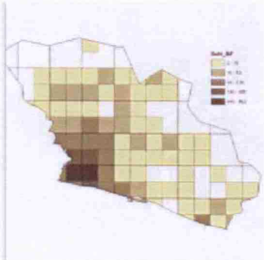
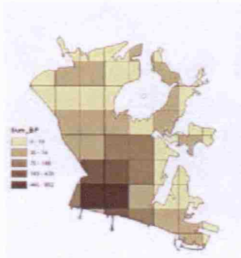
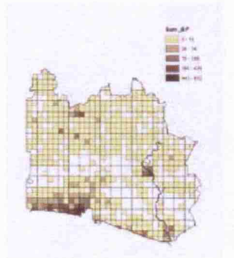
Area RP	05	07	10	Other
27				
30				

Area RP	05	07	10	Other
39				
44				

Area RP	05	07	10	Other
46				

Total Residential (RP) and Business (BP) per Quarter Square Mile

Grid BP	County	District	Urban	TTW
09				
10				

Grid BP	County	District	Urban	TTW
11				
22				

Grid BP	County	District	Urban	TTW
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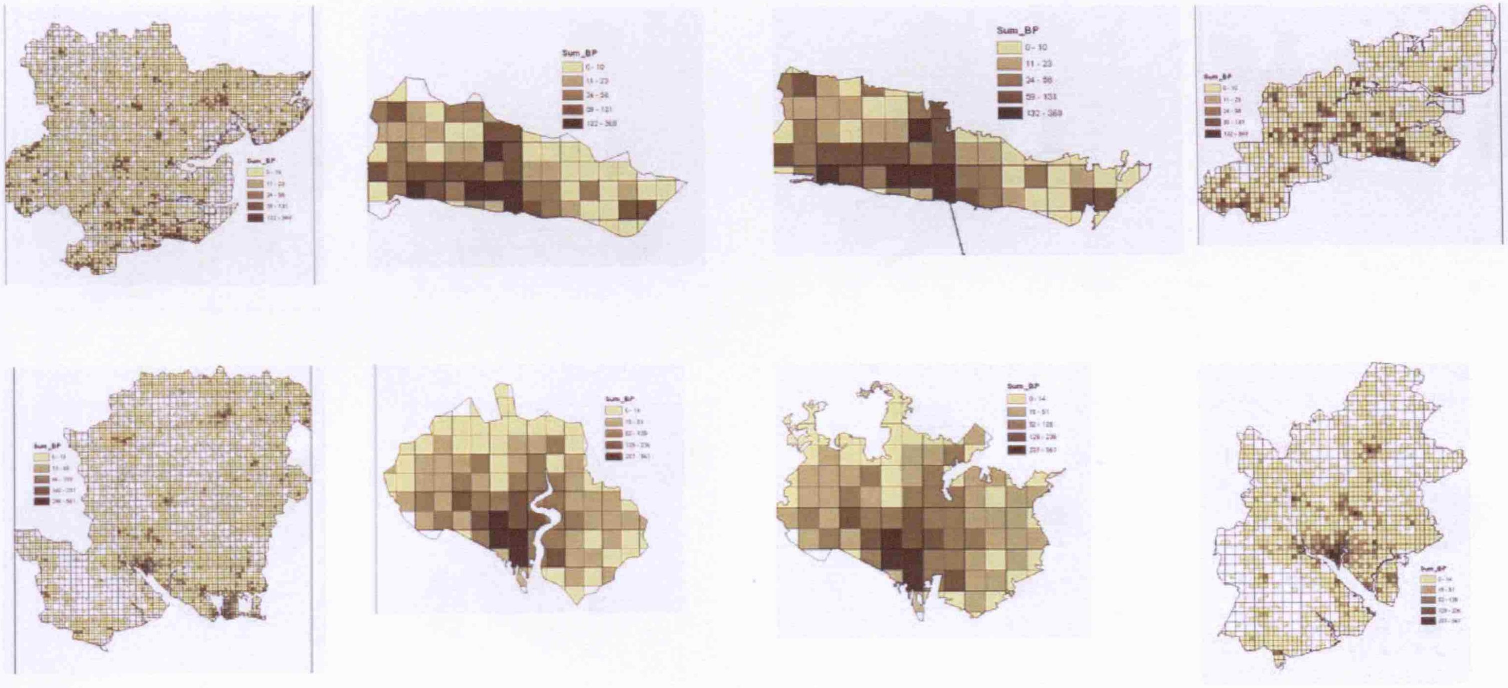
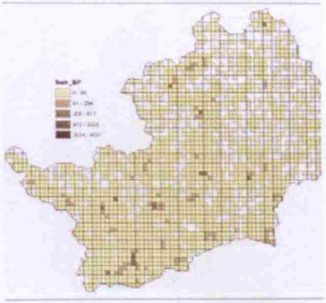
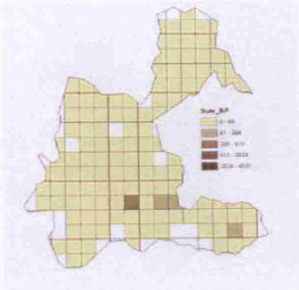
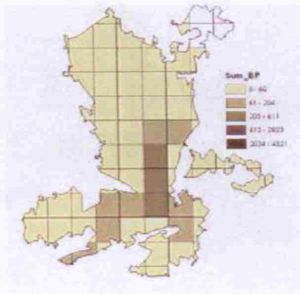
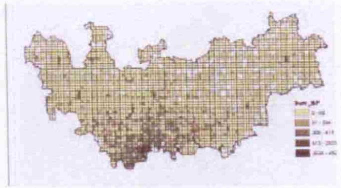
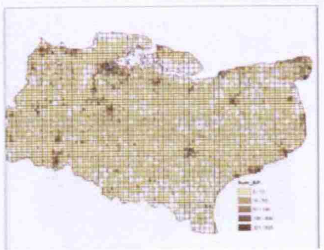
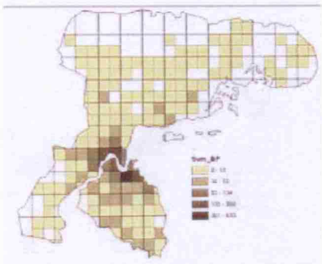
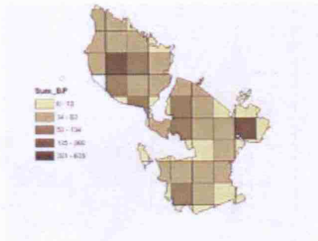
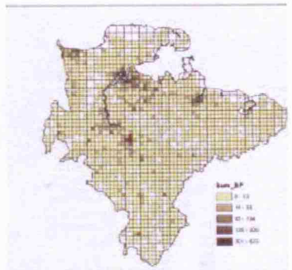
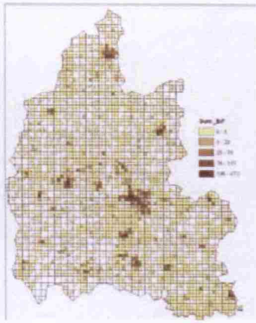
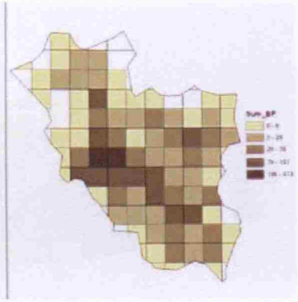
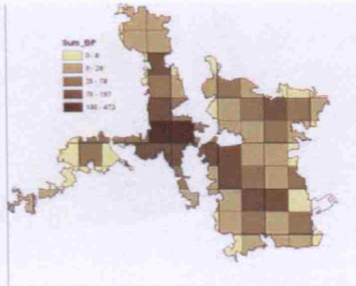
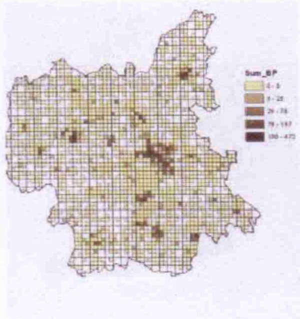
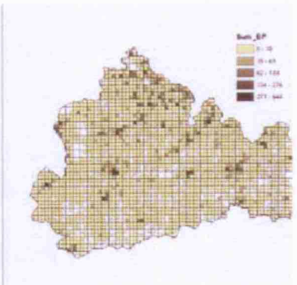
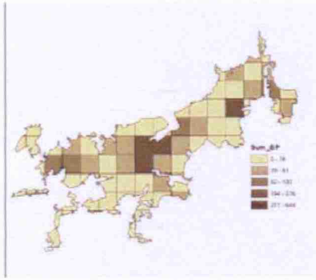
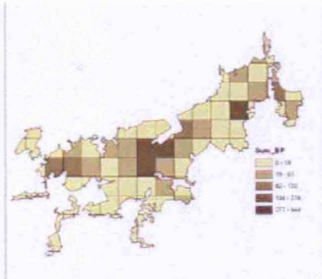
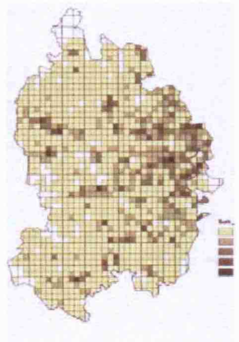
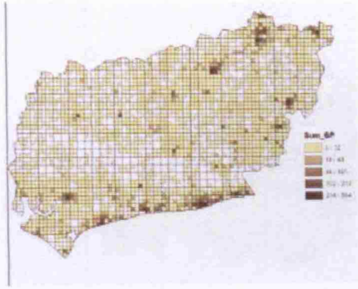
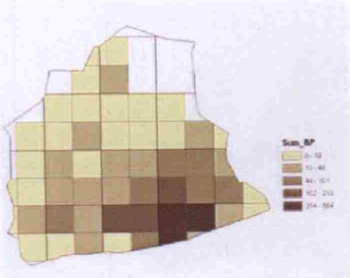
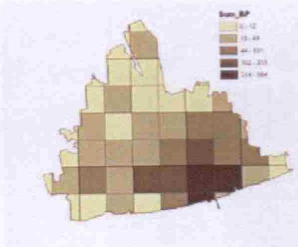
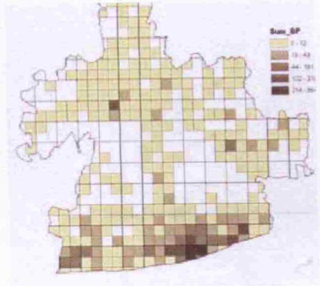
25				



Grid BP	County	District	Urban	TTW
27				
30				

Grid BP	County	District	Urban	TTW
39				
44				

Grid BP	County	District	Urban	TTW
46				

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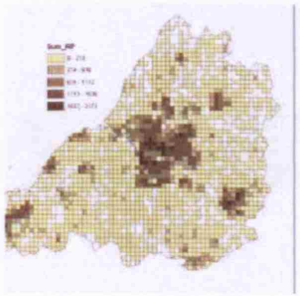
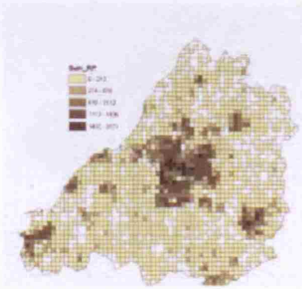
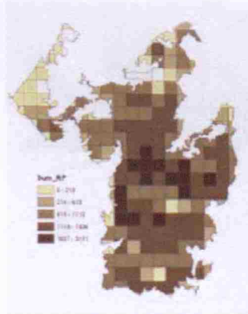
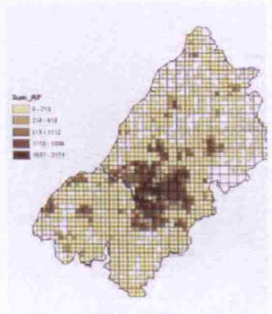
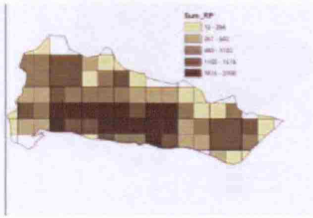
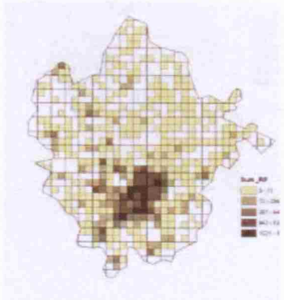
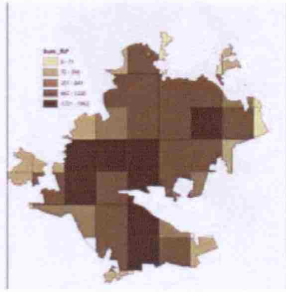
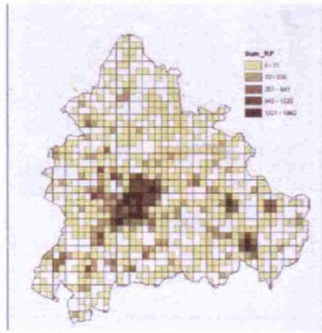
09				
10				

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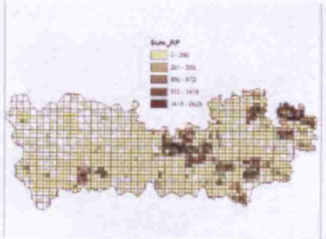
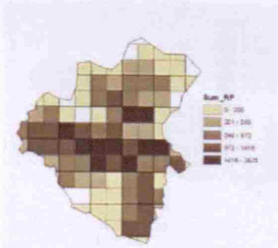
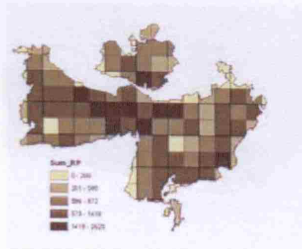
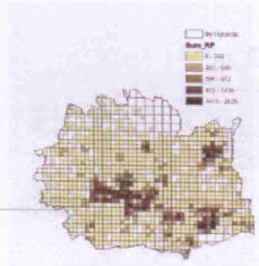
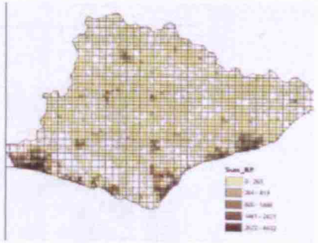
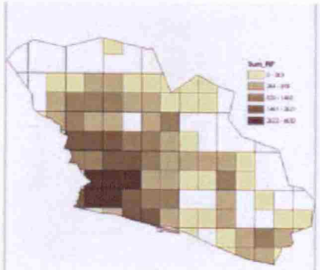
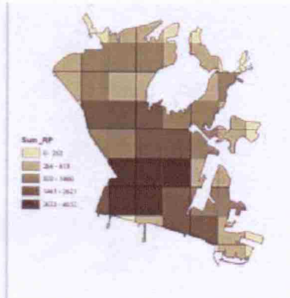
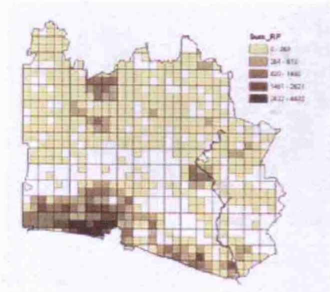
11				
22				

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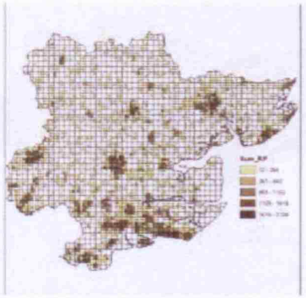
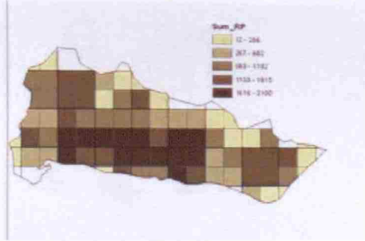
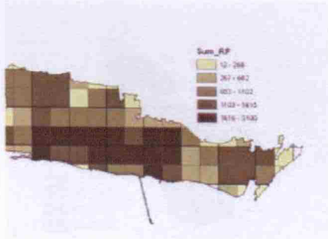
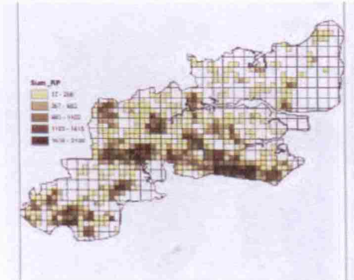
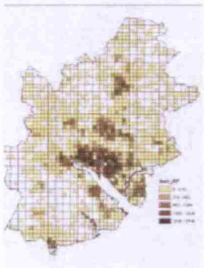
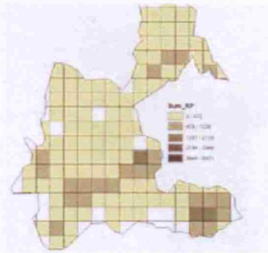
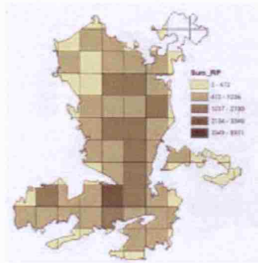
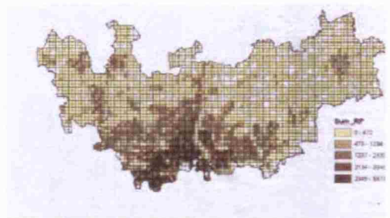
23				
27				

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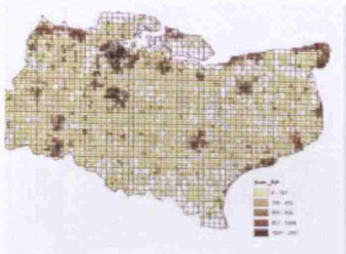
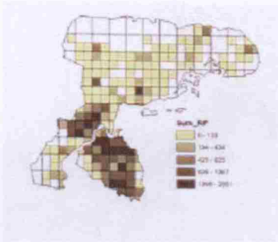
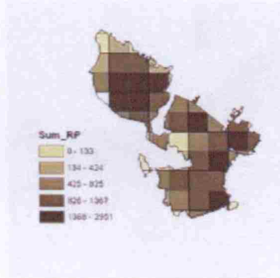
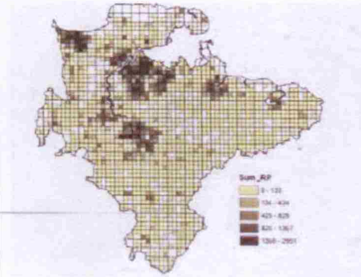
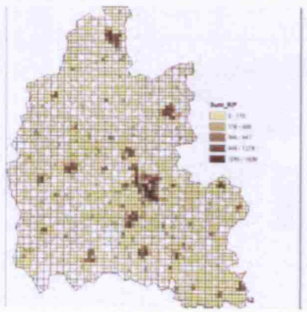
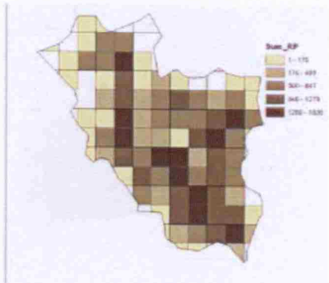
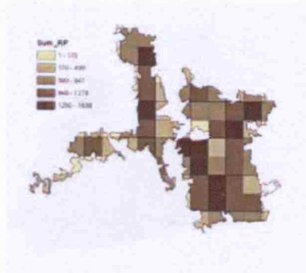
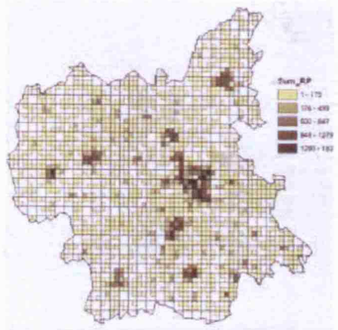
30				
39				

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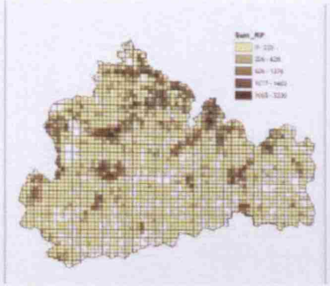
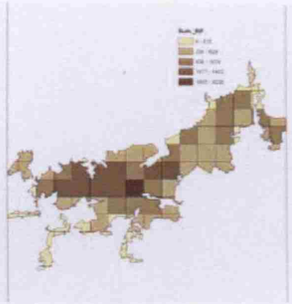
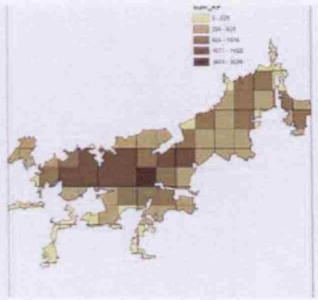
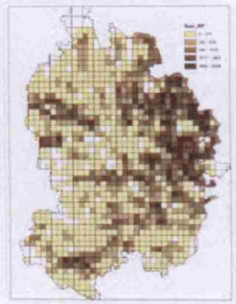
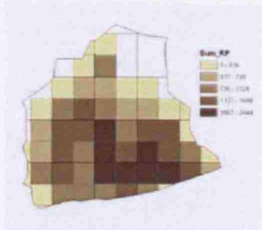
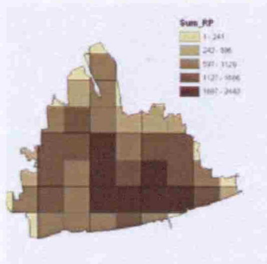
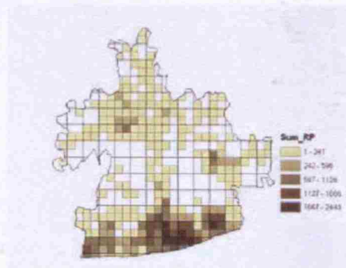
44				
46				

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